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MECHANICAL COMPOSITION OF SOME CHARACTERISTIC SOIL PROFILES FROM SOUTHERN ALBERTA

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Soils are composed of particles varying in size from gravel to those of colloidal dimensions. The study reported in this paper has to do with the percentage distribution of these soil particles in the sampled horizons of some typical profiles from southern Alberta.

Most of the samples analyzed were taken from the brown and dark brown soil zones of south and southeastern Alberta; that is, they have been formed under relatively arid soil conditions—conditions in which evaporation potentially exceeds rainfall.

The area described above was covered by the continental ice sheets which left a till mantle when the ice receded. This till is a mixture of materials transported from a considerable distance and materials obtained from the local parent rock, the latter possibly making up the greater percentage. The parent rock in this area is mainly from Upper Cretaceous to Lower Tertiary in age, but varies from fresh-water sandstone to marine shale. Post-glacial winds and waters have been responsible for sorting and re-transporting some of the surface material left when the ice retreated. The soil profiles, then, have been formed from a material that is a mixture of ground up rock (primary material) and weathered rock (secondary material).

MATERIALS AND METHODS

This work of mechanical analysis was undertaken to check the field grading of surface samples collected during the course of the present P.F.R.A. reconnaissance soil survey. Subsequent analyses of subsurface and subsoil horizons were made, and over 25 complete profiles have been analyzed. The original purpose of this latter study was to see if the elluvial movement of fine particles in the alkalinized profiles could be measured.

Considerable time was spent in obtaining a short method that was considered applicable. Bouyoucos (2) outlines a method for the mechanical analysis of soils by measuring the density of a soil suspension with a hydrometer. This is a more rapid method than the pipette method, and an endeavour was made to check these two methods using Alberta soils. The readings obtained in both cases were interpreted on a monographic chart prepared by Casagrande (3) for the solution of Stokes' law. This chart graphically relates temperature, specific gravity, time, and corrected hydro-

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meter reading. No attempt will be made in this paper to discuss any of the theory of mechanical analysis of soils or to give any complete bibliography of the work done on this phase of soil physics. Such discussions can be found in the works of Keen, Oden, Bouyoucos, Robinson and others.

The procedure using the hydrometer was as follows: A 50-gram sample of soil, excepting in the heavier soils where 33.3 grams were considered sufficient, was leached with about 750 cc. of distilled water to wash out any electrolytes present that might prevent deflocculation. Many Alberta soils contain considerable gypsum which may cause a reflocculation of a dispersed suspension. The filtered soil was deflocculated with sodium silicate and sodium oxalate and agitated for 10 to 12 minutes in a drink mixer. The suspension was made up to volume in a Bouyoucos cylinder and then kept in a water bath to limit temperature fluctuations. Hydrometer readings were taken at 40 seconds, 60 seconds, 15 minutes, 60 minutes, 80 minutes, 2 hours, 4 hours, and 12 to 16 hours. The sand greater than 0.24 mm. in diameter was separated out by means of a screen.

For the pipette method a 20-gram sample made up to volume was used. Samples were drawn off with a 20 cc. pipette in 50 seconds at 10 cm. depth, in 98 seconds at 20 cm. depth and in 80 minutes at 10 cm. depth. As stated earlier, these pipette readings were corrected for specific gravity and temperature on the monographic chart. In both methods the cylinders were agitated after each reading or sampling.

Check samples were stirred in the agitator for lengths of time varying from 5 to 30 minutes. Very little difference was noted in the results obtained. There was an indication, however, that for the samples used, there was as complete a dispersion at 10 minutes as at 30 minutes.

In general the soils analyzed in this study were relatively low in organic matter content. Check samples were analyzed, one treated with hydrogen peroxide and the other untreated. Very little difference in results from the two methods was obtained. There was, however, generally a slight but measureable increase in the clay content of the treated soils. Since the difference was slight and since it is thought that such a vigorous treatment as is necessary to destroy the organic matter may also affect the mineral structure, the samples were analyzed without any such pretreatment. It is realized that were such studies conducted on soils of a high organic matter content, certain difficulties might be encountered. In this connection, also, the calcium carbonate was not removed.

The greatest error in the hydrometer reading, according to Keen (4) occurs when there is the greatest density gradient. This was apparent in the 40- and 60-second hydrometer readings, and therefore the first two pipette samples were taken as a check. In practically all cases thes pipette samples gave a slightly higher percentage of particles than the hydrometer; the difference averaged slightly less than 3%. The 80-minute pipette readings averaged about 1% lower, and it was thought tha this might be due to a lag in particle fall in the more dense suspension used for the hydrometer method. Check determinations showed that, although there was a measureable lag in particle fall as a result of increasing the density of the suspension (using a larger sample), for samples between 20 and 50 grams it was small enough to disregard.

RESULTS

The results were plotted as summation curves on a standard screen scale. The readings on the Y axis give the total percentage of particles of smaller diameter; the X axis gives the particle size. The largest particle fraction is indicated on the curve at the point of the steepest slope. The percentage of particles between any two limits can be read directly from the graph.

The summation curves for 6 profiles analyzed by the hydrometer method are illustrated in this paper, profiles 1 to 6, inclusive. Since these 6 profiles are fairly representative of the profiles analyzed, the discussion will be mainly confined to them. These profiles illustrate, among other things, the following: (1) The type of profile and mechanical composition associated with some of the series types mapped by the Alberta soil survey; (2) a comparison of solonetz-like and normal profiles formed on relatively similar parent material; and (3) the extent to which southern Alberta soils can be said to have formed texture profiles. Brief descriptions of the profiles illustrated in Figure 1 are given below. The 3-digit number preceding the texture class appearing in these figures is the series designation. A complete definition of this series classification may be found in the later soil survey bulletins issued by the Department of Soils, University of Alberta, or in a paper by Bowser (1).

Profile 1

3.7.2. clay—A shallow black lacustrine clay. This profile is typical of a large area of clay lying just east of the foothills area of southwestern Alberta. The area in general is level to undulating and contains a considerable number of uniformly distributed, small, water-worn stones.

Profile 2

1.7.2. Si.C.L.—A brown, lacustrine, silty clay loam. This profile is from a level, stone-free area. Portions of the area contain considerable soluble salts. Patches of solonetz-like soils occur throughout the area.

Profile 3

1.7.4. Si.C.L.—A brown, lacustrine, somewhat solonized, silty clay loam. This profile comes from the same general area as described in Profile 2 above. It represents those portions of the area that have developed solonetz-like characters.

Profile 4

1.3.2. H.L.—Brown, sorted glacial, heavy loam. This profile is from an undulating, fairly uniform soil area. The parent material is glacial till, the surface of which may have received slight postglacial sorting. This profile is characteristic of much of the loam soil formed on ground moraine in southeastern Alberta.

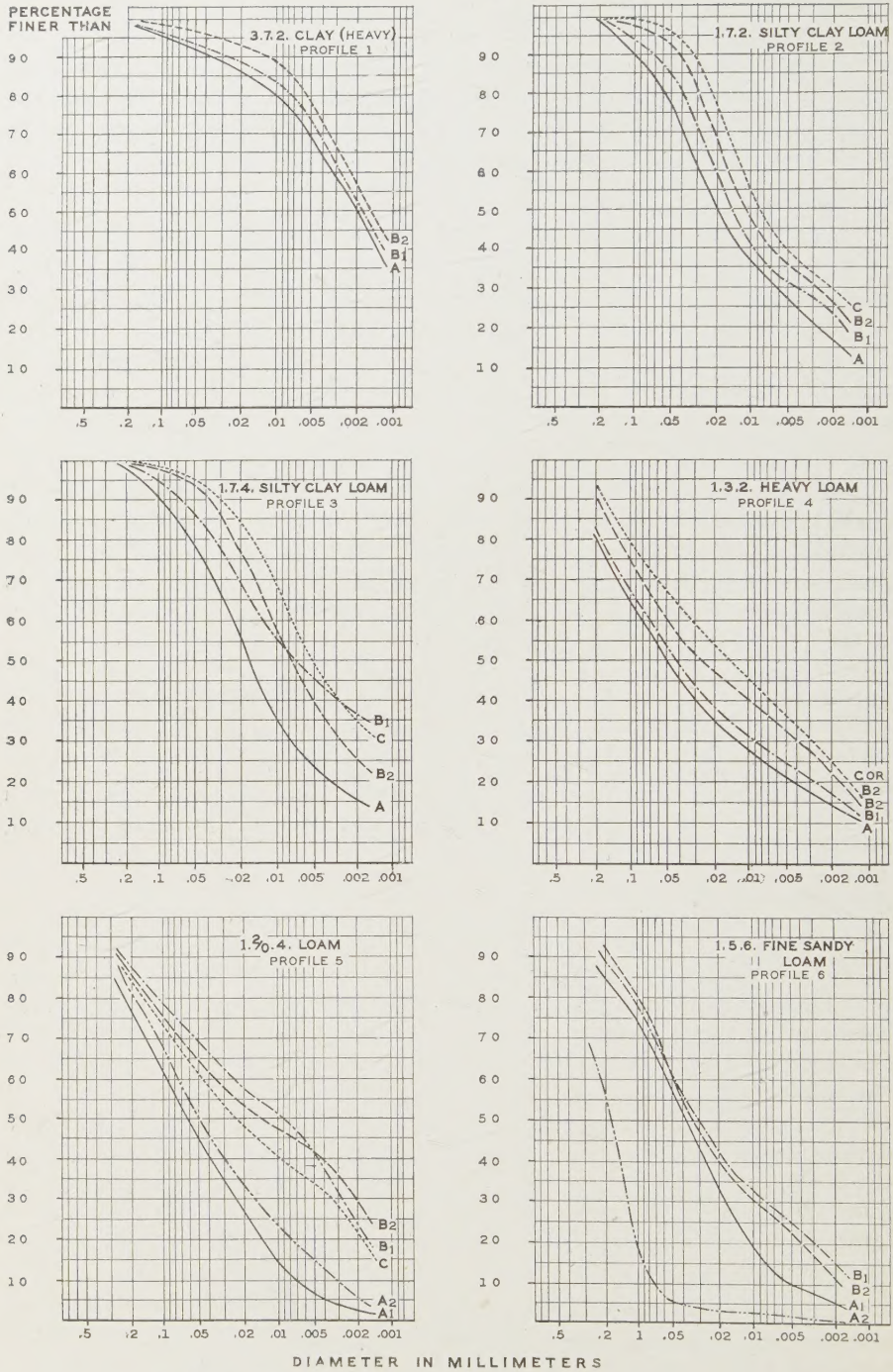

FIGURE 1. Summation curves for six soil profiles.

Profile 5

1.2/0.4. L.—Brown, glaciated, residual, somewhat solonized loam. This profile is from a gently rolling area in which the parent bed rock is quite close to the surface. Although glaciated, most of the material on which the profile is formed originates from the local bed rock which at this point is a transition between fresh-water Belly River sandy shales, and marine Bearpaw shales. Deep eroded pits, typical of solonized soil areas of southeastern Alberta are numerous in this area.

Profile 6

1.5.6. F.S.L.—Brown, alluvial, solonetz-like, fine sandy loam. This profile is from an undulating area of sandy soil. Although only a small percentage of the sandy soils of southern Alberta have a solonetz-like profile, where such profiles do develop they are quite similar in appearance to this one.

A comparison of the profiles illustrated shows a gradual change from a curve convex to the abscissa for the clay soils to one concave for the lighter textures. The steepest portion of the curve in the clay soils is at the small particle end of the X axis. In the silty soils it is approximately in the central portion, and for the loams and sandy loam soils the steep portion is at the coarse particle end. Approximately 50% of the surface horizon of the lacustrine clay soil (Profile 1) is particles less than 0.002 mm. in diameter; approximately 60% of the surface horizon of the lacustrine silty clay loam soil is made up of particles between 0.002 and 0.05 mm. in diameter. The sorted glacial heavy loam has 15% of particles less than 0.002 mm. in diameter and 50% of particles larger than 0.05 mm. The fine sandy loam surface soil has only 5% of particles less than 0.002 mm. It has 45% of particles larger than 0.05 mm. and 70% of particles larger than 0.02 mm. The above percentage composition figures are fairly typical of the soil textures mapped by the Alberta Soil Survey. A medium clay soil averages about 40% of particles less than 0.002 mm. The sameness of the curves throughout the profile in the lacustrine soils is worthy of note.

The accumulation of fine clay material in the illuvial B_1 horizon of the solonetz-like profile appears to be significant. Profiles 2 and 3, taken from the same area, show the same type of summation curve and approximately the same mechanical composition. The flattening out of the B_1 curve in Profile 3 showing a clay content greater than the C horizon, indicates deposition in this B_1 horizon. The small degree of slope of this curve at the small particle end suggests that it was very fine clay (less than 0.001 mm.) that has been translocated. Profiles 5 and 6 also indicate an accumulation of fine clay in the B_1 horizon. Profile 6 is of interest in that it shows an extreme leaching of the fine soil particles from the A_2 horizon.

There seems to be some indication of the formation of a texture profile in these soils. It is expected that the increase in weight with depth would be slight under the limited rainfall prevailing in this portion of Alberta. In areas where the parent material has undergone post-glacial sorting, stratification may mask an attempt by mechanical analysis to determine the extent of elluviation.

ACKNOWLEDGMENT

Acknowledgment is made to Dr. F. A. Wyatt and other members of the Department of Soils, University of Alberta, for helpful suggestions and criticisms.

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STUDIES ON SURFACE TAINT BUTTER

II. AN ODOUROUS COMPOUND IN SKIM MILK CULTURES OF *PSEUDOMONAS PUTREFACIENS*[1]

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The results of a chemical investigation of the compound responsible for the sweaty feet odour of skim milk cultures of *Pseudomonas putrefaciens* are presented in this paper.

MATERIALS AND METHODS

The same strain of *Ps. putrefaciens* was used in this study as in the previous investigation. The strain of *Bacillus subtilis* was from a stock culture kept in the Department of Dairying, University of Alberta.

The organisms were grown in skim milk made by reconstituting skim milk powder on a 1 : 10 basis, adjusting its pH to approximately 7.0 and autoclaving it at 15 pounds pressure for 20 minutes. Incubation was at room temperature for periods of approximately 2 weeks.

The Duclaux method was used for qualitative and quantitative analyses of volatile acid mixtures. The Duclaux constants in Table 1 were determined for a distillation apparatus of specifications given in Figure 1. The distillation procedure followed was similar to that used by Van Niel (8). The algebraic methods described by Gillespie and Walters (4) were used for the calculation of the compositions of mixtures containing two or three volatile acids.

TABLE 1.—DUCLAUX CONSTANTS

Volume of distillate	Acid in distillate			
	Formic	Acetic	Butyric	Isovaleric
ml.	%	%	%	%
30	19.0	24.0	47.4	69.4
40	26.4	32.5	59.6	81.1
50	34.5	41.7	70.4	89.2
60	43.4	51.2	79.5	94.2
70	53.5	61.5	87.0	97.3
80	65.2	72.5	92.9	98.8
Percentage of total which distilled	62.7	80.1	98.2	100.0

Quantitative measurements of volatile acids are expressed as the equivalent number of ml. of 0.1 N acid.

[1] Joint contribution from the Department of Biochemistry and the Department of Dairying, University of Alberta, Edmonton, and the Division of Bacteriology and Dairy Research, Science Service, Dominion Department of Agriculture, Ottawa. The data contained in this paper are taken from a thesis presented by the senior author to the University of Alberta in partial fulfilment of the requirements for the degree of Master of Science. Contribution No. 130 (Journal Series), from the Division of Bacteriology and Dairy Research, Science Service, Dominion Department of Agriculture, Ottawa.

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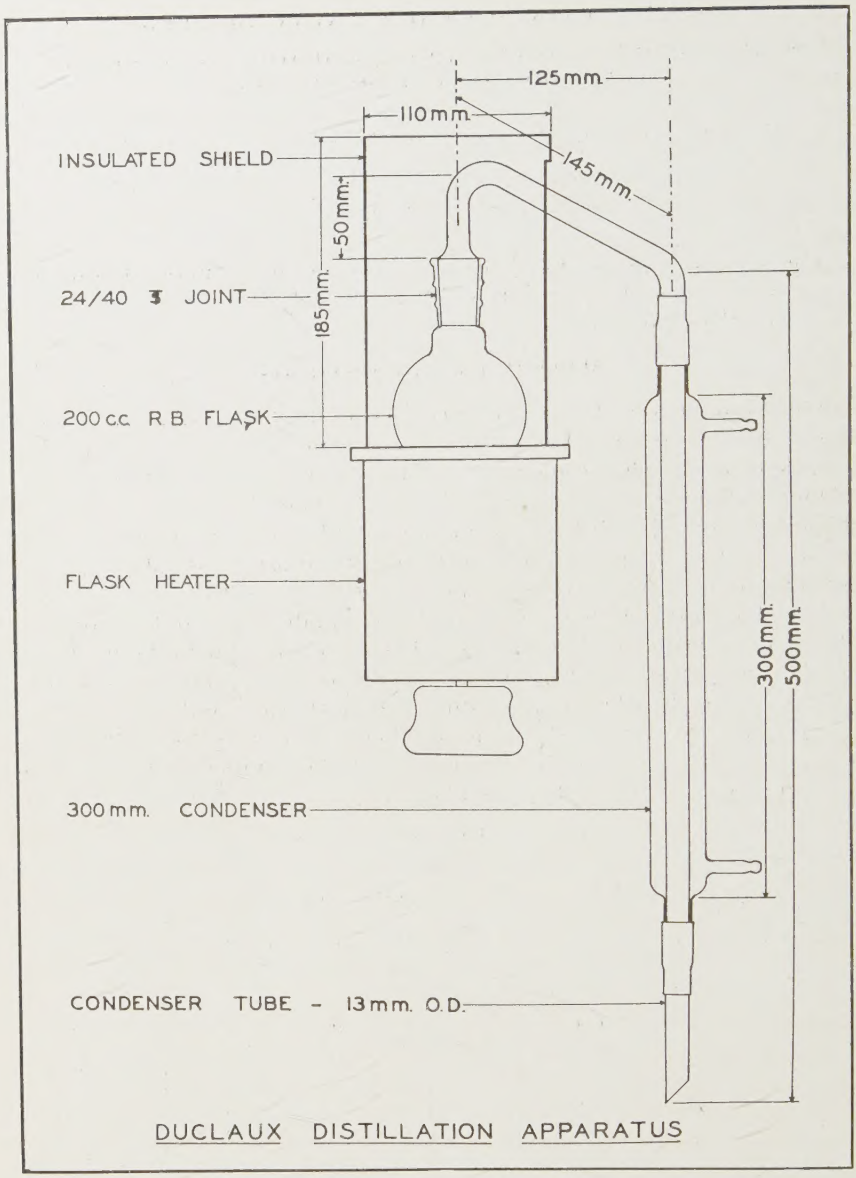


FIGURE 1.

Residues obtained by steam distilling acidified skim milk cultures and evaporating the neutralized distillates to dryness are referred to as "steam-distillate residues" throughout this paper.

EXPERIMENTAL

Preliminary Investigation of the Odourous Compound

The sweaty feet odour was not readily discerned from skim milk cultures of *Ps. putrefaciens* which had been made strongly alkaline, but it was very pronounced from acidified cultures.

It was possible to intensify the sweaty feet odour by steam distilling acidified *Ps. putrefaciens* cultures, neutralizing the distillate, evaporating the solution to dryness and finally acidifying the residue to release the odour. However, an acrid odour suggestive of the volatile fatty acids invariably accompanied the sweaty feet odour. Ether extraction removed the odourous material along with the volatile acids from acidic, but not from alkaline, solutions of the steam-distillate residue. The sweaty feet odour was not separated from skim milk by steam distillation of alkaline cultures. These results indicate that the odourous material has acidic properties.

Qualitative tests for the elements nitrogen, sulphur, phosphorus and the halogens, when applied to steam-distillate residue which had been fused with sodium or with a mixture of Na_2CO_3 and KNO_3, gave negative results. Since these elements were not detected in a residue from which the sweaty feet odour was readily released, it seemed probable that the odourous compound is a volatile acid containing only carbon, hydrogen and oxygen.

Separation of the Volatile Acids

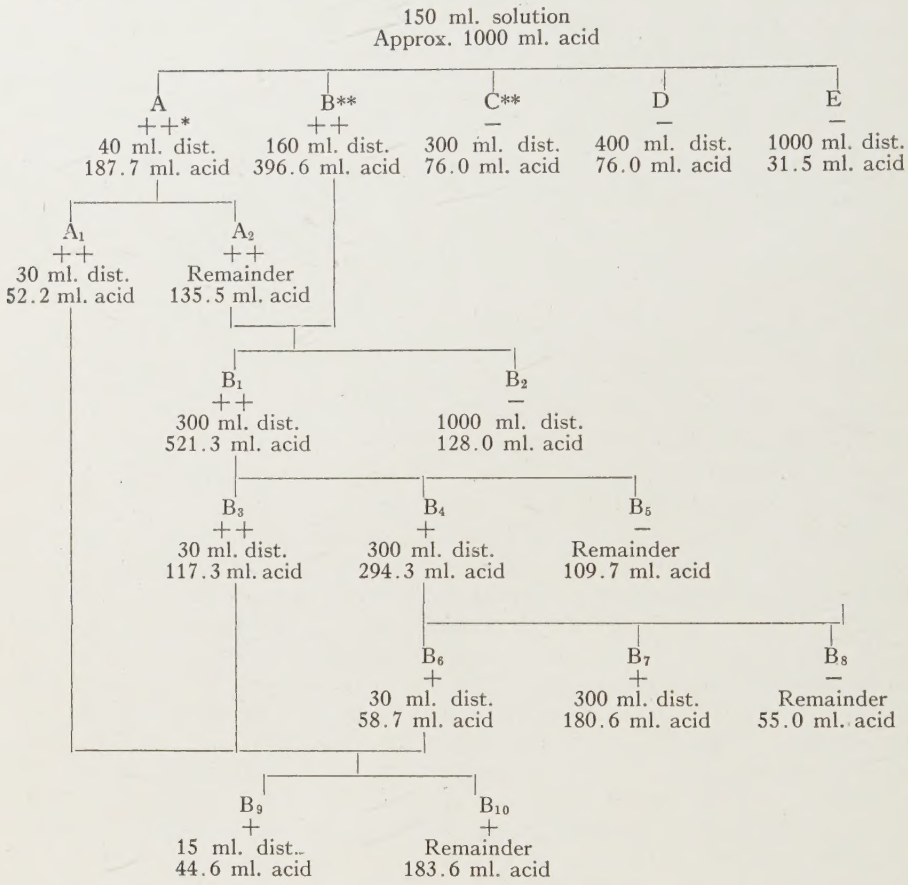
In order that a uniform supply of a concentrate of the odourous compound might be obtained for its identification, a routine procedure was developed for the preparation of steam-distillate residue on a rather large scale. Approximately 20 litres of skim milk culture of *Ps. putrefaciens* were mixed in a 50-litre carboy, the solution was adjusted to below pH 2.0 with H_2SO_4 and steam distilled. Approximately 10 litres of distillate were collected. This was neutralized with $Ba(OH)_2$, concentrated on a water bath to about 1 litre and filtered to remove the precipitated Ba salts of caproic acid and higher homologues of the fatty acid series. On acidification, this material gave no sweaty feet odour, and was thus discarded. The filtrate, brought to dryness, constituted the "steam-distillate residue".

A steam distillation procedure similar to that used by Parsons and Sturges (6) for the fractionation of volatile acid mixtures was applied to the steam-distillate residue. A solution containing the equivalent of approximately 1000 ml. 0.1 N volatile acid released from steam-distillate residue was fractionated by steam distillation at a constant volume of 150 ml. following the procedure described by Dyer (3). The tables determined by Dyer for his modification of the Duclaux method were used as guides to indicate the volumes of distillates which would have to be collected in order that the various volatile acids would be removed completely from the distillation flask. The data for the fractionation are summarized in Scheme I.

The progress of the steam fractionation was followed by smell and by Duclaux distillations. It was subsequently found that four acids were present in the steam-distillate residue. Since it is doubtful whether calculations based on single Duclaux distillations of 4-acid mixtures may be considered reliable, the compositions of the first fractions were not calculated. The steam fractionation eliminated one acid from certain

SCHEME I

DATA FROM STEAM FRACTIONATION OF ACIDS FROM STEAM-DISTILLATE RESIDUE



* Signs indicate the results of observations for the sweaty feet odour. (++ Odour pronounced, + Odour present, − Odour absent). The first figure below the sign gives the volume of distillate collected, the second indicates the equivalent volume of 0.1 N acid in the distillate.

** Small amounts of acid fractionated in preliminary experiments were added to fractions B and C.

fractions so that their compositions could be calculated. Table 2 contains the Duclaux constants for fractions D, B_8, B_9 and B_{10}, and also constants calculated for mixtures of the acids which these fractions contained. A satisfactory separation of isovaleric acid and of a mixture of acetic and formic acids was effected by this steam fractionation procedure. Calculations based on Duclaux constants indicated that butyric acid was also present in the mixture.

Identification of the Volatile Acids

It was assumed that formic acid would be present in the steam-distillate residue since numerous investigators have reported that it is produced during the distillation of an acidic carbohydrate solution. When solutions of the free acids from steam-distillate residue were oxidized with HgO

TABLE 2.—CONSTANTS FOR FRACTIONS FROM STEAM FRACTIONATION

Volume of distillate ml.	Fraction D		Fraction B_8		Fraction B_9		Fraction B_{10}	
	Exp.	Cal.[1]	Exp.	Cal.[2]	Exp.	Cal.[3]	Exp.	Cal.[4]
30	22.3	22.3	23.2	23.0	65.5	65.5	52.9	52.9
40	30.5	30.5	31.4	31.3	77.0	77.0	63.6	63.6
50	39.2	39.3	40.2	40.2	85.2	85.3	72.2	72.3
60	48.5	48.6	49.3	49.5	90.7	90.8	79.1	79.1
70	58.7	58.8	59.3	59.6	94.5	94.5	84.8	84.9
80	70.1	70.0	70.1	70.7	97.0	96.8	90.0	90.0

[1] Calculated for 34.5% formic, 65.3% acetic and 0.2% butyric acids.
[2] Calculated for 32.5% formic, 64.6% acetic and 2.9% butyric acids. The presence of a small amount of isovaleric acid, neglected in the calculations, caused poor agreement of the experimental and calculated constants.
[3] Calculated for 6.6% acetic, 4.0% butyric and 89.4% isovaleric acids.
[4] Calculated for 31.9% acetic, 9.4% butyric and 58.7% isovaleric acids.

by a procedure similar to that used by Osburn, Wood and Werkman (5), part of the volatile acid was destroyed. This evidence, along with calculations based on Duclaux constants, confirmed the assumption that the steam-distillate residue contained formic acid.

Fractions C, D, E, B_2 and B_8 from the steam fractionations were mixed and used for the identification of acetic acid. The formic acid was oxidized by refluxing the solution with HgO and the acids remaining were recovered by distillation. The mixture was again steam fractionated to eliminate some higher acids which still remained as impurities in the acetic acid solution. The purified acetic acid was Duclaux distilled; the first 70 ml. of distillate were collected as fraction I and the balance of the acid as fraction II. Each of these fractions was Duclaux distilled. The excellent agreement of the constants for these distillations furnished proof that the acid was pure acetic acid, not a mixture of acids (Table 3).

TABLE 3.—CONSTANTS FOR ACETIC AND ISOVALERIC ACID FRACTIONS

Volume of distillate ml.	Acetic acid		Isovaleric acid	
	Fraction		Fraction	
	I	II	I	II
30	23.9	24.0	69.6	69.4
40	32.6	32.6	81.2	81.1
50	41.7	41.7	89.2	89.2
60	51.2	51.3	94.3	94.2
70	61.4	61.5	97.5	97.3
80	72.5	72.6	99.0	98.8

Dyer's colorimetric test for acetic acid, when applied to the acid remaining after the Duclaux distillation of one of the fractions from the steam fractionation, gave a definitely positive result. Dyer's tests cannot be considered entirely reliable because they are not specific and they require relatively high concentrations of acids to give positive results.

Quinine acetate was prepared from the acetic acid fraction and also from authentic acetic acid following the procedure used by Phelps and Palmer (7). The salts were recrystallized twice from ethyl acetate and dried in a vacuum desiccator over KOH and H_2SO_4. The uncorrected melting points of these preparations were as follows:

Experimental Quinine Acetate (a)	126.0°
Authentic Quinine Acetate (b)	125.0 to 125.5°
Mixed (a) and (b)	126.0°
Reported by Phelps and Palmer	124° to 126°

These results confirm the identification of acetic acid.

The isovaleric acid in a mixture of fractions B_9 and B_{10} was precipitated as the silver salt, liberated by H_3PO_4 and recovered by distillation. A portion of this acid was Duclaux distilled; the first 20 ml. of distillate were collected as fraction I and the next 50 ml. as fraction II; then each fraction was again Duclaux distilled. The concordance of the two sets of constants provided evidence that the acid was relatively pure isovaleric acid (Table 3).

Dyer's colorimetric test for valeric acid, when applied to isovaleric acid which had been precipitated as the silver salt, gave a positive result.

p-Phenylphenacyl isovalerate was prepared from the isovaleric acid fraction and also from authentic isovaleric acid by the procedure described by Drake and Bronitsky (2). The products were recrystallized twice from 50% ethanol and dried in a vacuum desiccator. The uncorrected melting points of these products were as follows:

Experimental p-Phenylphenacyl Isovalerate (c)	75.5° to 76.0°
Authentic p-Phenylphenacyl Isovalerate (d)	75.8°
Mixed (c) and (d)	75.8°
Reported by Drake and Bronitsky	76°

These results confirm the identification of isovaleric acid.

A separation of butyric acid from the steam-distillate residue was not effected by steam fractionation. However, after the presence of acetic and isovaleric acids had been confirmed, it was considered that the Duclaux constants provided sufficient evidence to justify the conclusion that butyric acid was present.

Quantitative Determinations of Volatile Acids

A relatively high yield of steam-distillate residue was obtained from steam distillations of sterile skim milk. It was necessary to determine the quantitative composition of the volatile acid mixture in steam-distillate residue from sterile milk as well as from *Ps. putrefaciens* cultures in order to determine the effect of the growth of the organism in milk on the volatile acids recovered by steam distillation. Skim milk cultures of *B. subtilis* were also investigated so that the results of the distillations of *Ps. putrefaciens* cultures might be compared with those for a common proteolytic organism.

One-litre portions of sterile milk or 2-week cultures of the organisms were acidified to below pH 2.0 by the addition of 50 ml. of 60% H_3PO_4

and steam distilled at constant volume until 4 litres of distillate were collected. The acid distillates were titrated with $Ba(OH)_2$ and evaporated to dryness. The volatile acids from a number of distillations were mixed, oxidized with HgO, distilled to recover the acids remaining and titrated. The reduction in acidity was expressed as formic acid since it was assumed to result from the destruction of formic acid. Duclaux constants were determined for the acid mixture remaining after the oxidation. The mixture was extracted with benzene, and Duclaux constants were determined both for the acids dissolved in the benzene and for those left in aqueous solution. The benzene extraction was included as a check on the qualitative composition of the volatile acid mixture as calculated from Duclaux constants. If two acids intermediate between acetic and isovaleric were present in the mixture instead of butyric acid, it is highly improbable that the two acids would be extracted by benzene in such proportions that the Duclaux constants for the acids dissolved in the benzene and for those remaining in aqueous solution would both indicate the presence of butyric acid. The volatile acids obtained by steam distillations of 1-litre portions of sterile skim milk, *Ps. putrefaciens* cultures and *B. subtilis* cultures are summarized in Table.4

Table 4.—Volatile acids from steam distillations

	Sterile milk	*Pseudomonas putrefaciens* cultures	*Bacillus subtilis* cultures
Total acidity	44.0	65.8	67.4
Formic acid	17.9	20.1	16.3
Acetic acid	24.2	40.0	39.5
Butyric acid	0.2	1.3	2.3
Isovaleric acid	0.4	1.9	8.1

DISCUSSION

It was concluded that the steam-distillate residue from acidified cultures of *Ps. putrefaciens* contained formic, acetic, butyric and isovaleric acids. The quantitative acid determinations summarized in Table 4 are not, necessarily, measures of the volatile acids produced by the bacteria because:

1. It cannot be taken for granted that the increase in the volatile acidity of the cultures resulted from the production of acids in the free form by the bacteria. Part of the increase may have resulted from a secondary reaction such as the decomposition of partially hydrolyzed proteins under the combined action of heat and strong acids during the steam distillation.

2. The steam distillation procedure used did not quantitatively separate the volatile acids from the acidified cultures.

In all cases the sweaty feet odour was concentrated along with the isovaleric acid, but a separation of the sweaty feet odour from isovaleric acid was not effected. The intensity of the sweaty feet odour was not proportional to the concentration of isovaleric acid. From an inspection

of Table 4 it may be seen that the steam distillate from *B. subtilis* cultures contained more than 4 times as much isovaleric acid as that from *Ps. putrefaciens* cultures. Although the sweaty feet odour was readily detected from *Ps. putrefaciens* cultures, only once was it detected from *B. subtilis* cultures. In this case, the sweaty feet odour was observed when the condenser cooling water was not turned on at the start of a steam distillation of an acidified *B. subtilis* culture and the vapour was allowed to escape. Another observation which showed that the intensity of the sweaty feet odour was not necessarily proportional to the concentration of isovaleric acid was made during the steam fractionation experiment. Fractions A_1 and B_3, which had a pronounced sweaty feet odour, and B_6, from which the odour was readily detected, were mixed and fractionated into fractions B_9 and B_{10}. The sweaty feet odour was not detected when these fractions were first examined, but on the following day when the observations were repeated, the odour was very pronounced.

The common odour of isovaleric acid is somewhat similar to the sweaty feet odour, but a person familiar with the two odours can readily distinguish them. The sweaty feet odour has been associated with isovaleric acid from sources other than *Ps. putrefaciens* cultures. The sweaty feet odour was not detected from one preparation of isovaleric acid purchased during this study, but it was readily observed from a less pure, monohydrated acid purchased from another supply house. Bernthsen (1), in listing the sources of isovaleric acid, stated: "It is found . . . . in the perspiration from the foot . . . ".

This evidence indicates that there is a definite connection between isovaleric acid and the sweaty feet odour. Under certain unknown conditions, perhaps of concentration, temperature, humidity, E_h, etc., the sweaty feet odour seems to arise from isovaleric acid. However, since the sweaty feet odour is not the common odour of isovaleric acid, it is possible that the isovaleric acid undergoes a chemical change to give this odour. This chemical change might be an oxidation of the isovaleric acid, either in the air or at the surface of the medium in which the isovaleric acid is dissolved. The opinion has been expressed (9, 10) that *Ps. putrefaciens* may produce in milk a substance which is in a reduced state and, if odourous, is present in insufficient concentration to be detected by the sense of smell. Exposure to air oxidizes this material to a detectably odourous stage. More strongly oxidizing E_h levels will reversibly change the compound to a non-odourous state.

The evidence reported favours the conclusion that the substance causing the sweaty feet odour is closely related to isovaleric acid. However, an explanation for the differences in the intensity of the sweaty feet odour arising from isovaleric acid from different sources is not yet evident.

In this study as in the previous communication (10) attempts were made to produce the surface taint defect in butter by churning cream to which had been added portions of isovaleric acid isolated in various stages of purification from *Ps. putrefaciens* cultures. Although the odours of some butters produced in this way bore a close resemblance to that of typical surface taint butter, in no case was there complete agreement that such a butter might be considered as typical surface taint. However, it

cannot be concluded from such experiments that isovaleric acid is not the constituent responsible, at least indirectly, for the characteristic odour of surface taint butter.

SUMMARY

From the results of Duclaux distillations, it was concluded that the acid mixture obtained by steam distillation of acidified skim milk cultures of *Ps. putrefaciens* contained formic, acetic, butyric and isovaleric acids. The identification of acetic and isovaleric acids was confirmed by determinations of the melting points of suitable derivatives.

The acid mixtures obtained by steam distillation of acidified sterile skim milk, *Ps. putrefaciens*, and *B. subtilis* cultures had the same qualitative, but different quantitative, composition.

It is concluded that the substance causing the sweaty feet odour of skim milk cultures of *Ps. putrefaciens* is closely related chemically to isovaleric acid.

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10. I. Odour production by *Pseudomonas putrefaciens*. Sci. Agric. 22 : 277-286.
11. II. An odourous compound in skim milk cultures of *Pseudomonas putrefaciens*.
12. III. Some further characteristics of *Pseudomonas putrefaciens*. To be published.
13. IV. Distribution and taxonomy of *Pseudomonas putrefaciens*. To be published.
14. V. The growth of *Pseudomonas putrefaciens* in butter. To be published.
15. VI. Other bacterial species as causal agents. To be published.

CHEMICAL WEED CONTROL IN LAWNS[1]

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This subject, so far as information available to the writer is concerned, cannot be outlined in clear and concise terms applicable to all weeds which infest lawns under all the variable climatic and soil conditions where turf growing is practised. The subject of weed control on lawns is also closely linked with general turf management which includes such items as rolling, watering, raking, spiking, cutting, removal of clippings, fertilizing, worm control, drainage, and top dressing. These mechanical operations, while not discussed here in detail, must be carried out to the optimum degree and when so done are of great importance in curtailing weed invasion.

The conclusions arrived at are the result of work carried out at the Dominion Experimental Farm, Agassiz, B.C., during the past seven years under a wide variety of conditions as to weather, season of application, and age, density and kind of grass.

WEED SPECIES

The following are the kinds of weeds which are of most importance in established lawns throughout Canada: spring dandelion (*Taraxacum officinalis*), catsear (*Hypochaeris radicata*), mouse ear chickweed (*Cerastium vulgatum*), broad leaved plantain (*Plantago major*), narrow leaved plantain or ribwort (*Plantago lanceolata*), selfheal (*Prunella vulgaris*), yarrow or milfoil (*Achillia millifolium*), pearlwort (*Sagina procumbens*), mosses, wild white clover under certain conditions, annual poa (*Poa annua*), crab grass, *Digitaria* species and English daisy (*Bellis perennis*).

CHEMICALS FOR WEED CONTROL

The following are the more important chemicals for turf treatment:

Sulphate of ammonia when consistently used as a fertilizer (1).

Iron sulphate (1) when used in solution as a spray or in the "calcined" or "exsiccated" form when mixed with sand or sulphate of ammonia.

Oils, as referred to by Loomis (5) and Woods (13), when used as all-over sprays or direct plant injections. Oil sprays of value include coal oil or kerosene, stove oil and diesel oil. The efficiency of oils may be based on their unsaturated hydrocarbon (5) content or more conveniently on their Acid Heat Test, which information is available directly from oil refineries. Stove oil with an acid heat test of 4 has proved the most satisfactory kind.

Arsenicals, more especially sodium arsenite, extensively dealt with by the U.S. Golf Association Green Section (8) and the New Zealand Journal of Agriculture (3) and the Second and Third Annual Reports, New Zealand Green-keeping Research (9).

Sinox or dinitro-ortho-cresylate, developed in France in 1933 and used by Westgate and Raynor in California (12).

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Meo 181 or mercurated-ethyl-stearate in kerosene, as referred to by Hanley and Weinard (2), Ralson, Christensen and Josh (10), and Silversides and Olson (11).

Copper sulphate (13), more especially for controlling *Hypochaeris radicata*.

Copper nitrate, McRostie and Silversides (7).

Calcium cyanamide is widely known to have a lethal effect on weed seeds in soil and is of value applied before seeding down a new area.

Sodium and calcium chlorates are herbicides extensively used on field weeds and to a lesser extent as all over sprays on lawn grasses. There is danger, however, of too severe burning.

There are numerous other chemicals capable of killing weeds in lawns, some of which are used extensively under field crop conditions. Evidence pertaining to their value under turf conditions is not as extensive as for those mentioned above and they will not be referred to in this paper. A number of these chemicals are reviewed by Long (4).

CONFLICTING EVIDENCE

There is a large amount of contradictory as well as corroborative evidence as to the effect of herbicides on weeds. Loomis (5) reports kerosene as being satisfactory for controlling dandelions under Iowa conditions while little effect has been obtained on broad leaved plantains, while Woods (13) at Agassiz has reported a high degree of control with plantains and less effective though a good measure of control on dandelions. Madden (6) in New Zealand reports pearlwort controlled with dilute solutions of arsenic pentoxide, while preliminary tests at Agassiz have not shown this to be the case. Westgate and Raynor (12) in California have obtained satisfactory control of dandelion and broad leaved plantain with two spring sprays of Sinox at 1 to 20 and 1 to 28 dilutions. At Agassiz single fall sprayings in 1938 and 1939 and in spring (1940) two sprayings have not given a high degree of control, though appreciable and encouraging responses have been obtained. McRostie and Silversides (7) in Manitoba report satisfactory control of dandelions with copper nitrate. Comparable results have not been obtained at Agassiz, also unsatisfactory results have been reported to the writer in correspondence from the Ontario Agricultural College. From the University of Alberta, College of Agriculture, correspondence states that in one test copper nitrate has been satisfactory while in a second it has not proved so. The Manitoba Agricultural College and the Saanichton Experimental Station in correspondence report highly satisfactory results from Meo 181 in controlling dandelions. At the Agassiz Experimental Farm spring and fall treatments in 1940 have not given satisfactory control of weeds except where there has been a too severe burning of the grass with resultant poor recovery. With oil and copper sulphate sprays at Agassiz from time to time there has been considerable variation in the results obtained, especially between spring and fall sprays, some influence being exerted by the temperature which follows spraying.

CONDITIONS AFFECTING USE OF CHEMICALS

The above contradictory results could be enlarged upon, but they suffice to show the complexity of the problem. Numerous conditions are known to be responsible for these variable results. At Agassiz, when using

oil and copper sulphate sprays, much more satisfactory results have been obtained with September sprays than with the same material applied in May. One application of copper sulphate applied March 11 (rain followed within 3 hours) had no effect on catsear, while a single spray in dry weather in September caused all foliage to be burned up. The value of fall spraying, from Agassiz experience, must be particularly stressed. The U.S. Golf Greens Association (8) recommends fall applications for sodium arsenite, and states that high temperatures increase effectiveness on weeds but cause proportionately more injury to turf. Armour and Company, for the use of Meo 181, recommend temperatures 70° F. or above. July applications at the Manitoba Agricultural College (11) have given better results than June sprays, though partly due to less reinfestation, and it is assumed here that temperatures in July would normally be above 70°. At Agassiz (13) temperatures above 70° with oil sprays caused more burning to grass and less injury to weeds than when temperature was lower, such as prevails during cloudy, dull weather. Loomis (5) obtained comparable results in Iowa. McRostie and Silversides (7) recommend that copper nitrate sprays be applied in Manitoba during July and August when temperatures are high. Madden (6) for New Zealand recommends late summer or fall sprays when using sodium pentoxide. In California (12) spring treatment has been given when using Sinox on dandelions, and the manufacturers' recommendation is to make applications when the plants reach the full bloom period, but spraying must be done before hot weather occurs.

Moisture is a contributing factor on the effect of herbicides. At Agassiz after using oil sprays showery weather has not apparently affected the value of the materials used. Cool showery weather is on the whole beneficial. This is a normal expectation considering that water does not dilute an oily covering. Loomis (5) has found dull, cool weather best for oil sprays. In California (12) good control was obtained with Sinox when water was withheld for 3 days after spraying, but there was very little control when water was applied 1 day after spraying. In New Zealand, Madden (6) when using arsenic pentoxide suggests watering a week after spraying if the soil is dry, and states that the foliage should be dry at the time of application. In Turf Culture (8) the statement is made that arsenicals applied to wet foliage cause more killing of weeds and grass than when applied to dry foliage, but proportionately more to grass than to weeds. Watering after treatments has lowered the herbicidal effect of arsenicals. Likewise a high degree of soil moisture lowers the treatment value while a dry soil delays grass recovery.

The dominant type of grass in a treated turf has a bearing on the effectiveness of chemicals. Oil sprays at the Agassiz Experimental Farm have caused less injury to bent grasses than to fescues, and the bents have made quicker recovery. Bluegrass turf compared to the other two has been relatively poor in density of stand and results obtained are not comparable. The U.S. Golf Green Association (8) states that Kentucky Blue and Bermuda grass are more resistant to chemicals than fescues and bents, the former more so than the latter. Westgate and Raynor (12) state that Kentucky Blue and Bermuda grass are more resistant to chemical injury than such matting grasses as the bents.

Weeds in themselves show a marked difference or selective action to different chemicals. Some weeds are highly resistant to one chemical while others show a marked susceptibility.

Temperature, soil moisture, soil type, rainfall and the kind of turf, including density and vigour, all have a bearing on the success of chemical control of weeds, and daily and periodical fluctuations of temperature and moisture in part at least account for the different results obtained in many experiments and the disappointing results in many small trials. Wide geographical differences are of importance, due at least in part to the factors enumerated above.

RECOMMENDATIONS

In spite of the conflicting evidence referred to, definite information can be given on the use of chemicals for weed control in lawns. Preliminary trials should be made on small areas in somewhat out-of-the-way places in order to determine the effect of treatments undertaken. It is not advisable to undertake large scale control until definite information is available from small plots. Should preliminary trials with any of the recommended materials prove to be a failure careful study should be made to discover a possible cause, bearing in mind the limiting factors referred to above. Repeated trials may be necessary before the correct time, the correct climatic conditions, or the most suitable chemical is found for a specific weed under local conditions. The nature and vigour of the turf to be treated are important considerations. When the weed population is very heavy it must be determined if it is worth while to bring the area back. Unless there is a sufficient amount of grass to take up the area occupied by weeds, seed will have to be sown as soon as the weeds are controlled, otherwise a new weed population will commence to follow the one destroyed. Nature makes a strong effort to clothe the soil.

Fertilizer

The first essential in weed control is to have good vigorous turf composed of the most suitable grass for local conditions. Apart from numerous mechanical operations listed in the opening paragraph the correct use and kind of fertilizer must be closely followed. This cannot be dealt with in detail here. Reference should be made to Dawson's book on Practical Lawn Craft (1). In the experiments carried out by Dawson at the St. Ives Research Station, Yorkshire, it has been found that regular applications of sulphate of ammonia are by themselves of great value in preventing weed invasion. The effect of sulphate of ammonia is both direct as to weed inhibition and indirect on account of stimulation to grass growth. Nitrate of soda will not serve the same purpose. Ammonium phosphate is also recommended but does not act as well in controlling wild white clover as does sulphate of ammonia alone. Some phosphate and potash, however, is required at intervals to supply the grass with these necessary elements.

Worm Control

Worms are a factor in aiding weed invasion and must be controlled. Turf cannot be smooth and velvety where there are numerous worm casts. Worm casts bring weed seeds to the surface which would otherwise remain dormant and the casts at the surface form fertile areas for weed seeds to

germinate. Regular applications of sulphate of ammonia act as a direct control (1). Other materials are: corrosive sublimate, copper sulphate at 1 to 500 dilution at $\frac{1}{2}$ gallon per square yard; lead arsenate at 5 to 10 pounds to 1,000 square feet; and various commercial wormicides. At the Agassiz Experimental Farm lime sulphur diluted 1 part to 200 of water and applied at 2 gallons to a square yard brings a larger number of worms to the surface than any other method tried. The lime sulphur treatment does not kill a high percentage of worms. Sinox, as referred to later, has value as a wormicide. Reference should be made to (1, 8 and 6).

Copper Sulphate

At Agassiz Experimental Farm (13) two September sprays of copper sulphate have controlled catsear, and is the recommended treatment for this weed. Three spring sprays have not proved satisfactory. The rate of application has been a 10% solution, one gallon covering 250 square feet. Rain following shortly after spraying nullifies the desired effect. The second treatment should follow in 3 weeks when new leaves are again forming. Copper sulphate as applied for weeds has proved of considerable value in controlling moss and is recommended for this purpose.

Oil

Kerosene, stove oil and diesel oil have proved to have herbicidal value at Agassiz (13) and kerosene in Iowa (5). At Agassiz, stove oil with an acid heat test of 4, applied at 1 gallon to 200 square feet, has proved to be the most effective treatment for broad leaved plantain and is of value for dandelions and catsear. Single fall applications in any one year have proved adequate. Diesel oil, acid heat test 9, has also proved of value, though it often causes considerable turf injury. There are chances of too much turf injury from this grade of oil to recommend it. Diesel oil on fescue lawns has eradicated wild white clover without excessive turf injury, while kerosene and stove oil have not. Diesel oil, if used, should not be applied at heavier rates than 1 gallon to 300 square feet. Oil sprays at Agassiz have not in any way controlled mouse ear chickweed and pearlwort. In fact in plots infested with these weeds, oil sprays, by burning the grass, have enabled them, especially chickweed, to grow more vigorously. Additional treatment, as noted below, to control these weeds must be given with iron sulphate and sulphate of ammonia for pearlwort, and sodium arsenite for chickweed.

Iron Sulphate

The value of iron sulphate has been well known for many years. Repeated applications of a 20% solution are reported as successful in controlling dandelions. No such tests have been conducted at Agassiz. In the calcined form mixed with sulphate of ammonia and sand it has great value for spot applications or for broadcasting. Detailed results have been given by Dawson (1). At Agassiz, it has been found of particular value for pearlwort. A mixture made up of 3 parts iron sulphate, 2 parts sulphate of ammonia, and 15 parts of dry sand sprinkled over infected areas by hand or from a tin can with holes in the bottom has given satisfactory control. The above amount will cover about 150 individual plant clusters, or 7 ounces of the above mixture will cover approximately 1 square yard. The grass will turn black after treatment. Severe burning and slow grass

recovery will result if applied too heavily and poor weed control if applied too lightly. Careful trials should first be made. This mixture is also effective against moss and mouse ear chickweed. For the latter, as noted later, sodium arsenite is preferable. In spot treatment of creeping weeds care must be taken to cover the full area of infection. For broadcasting a mixture made up of 3 parts by weight of sulphate of ammonia, 1 part calcined iron sulphate and 20 parts sand applied at 4 to 6 ounces per square yard is recommended by Dawson (1).

Sodium Arsenite and Arsenic Pentoxide

These arsenicals are possibly more extensively used as herbicides for lawn purposes than any other material. Grades of material will vary in their percentage of arsenic. Approximate figures give a value of 13 ounces of arsenic pentoxide to equal 16 ounces of sodium arsenite. Detailed results on these materials may be found in (8, 3, 9 and 6). Preliminary trials were started at Agassiz in the spring of 1940 with sodium arsenite at the rate of 1 ounce in 1 gallon of water applied to 250 square feet. The area was infested chiefly with dandelion, plantain and yarrow. Three spring and one fall applications were given. Following the first treatment two succeeding ones were applied when leaves on weeds were again showing, which was after an interval of about three weeks. The fall spray was given September 15. Severe burning to grass and weeds resulted. After these applications weed growth was still plentiful, though not as prolific as before treatment Grass showed considerable injury. The results to date would indicate that for Agassiz conditions weaker dilutions, $\frac{1}{2}$ ounce to 1 gallon, are advisable. It should also be borne in mind that references listed above suggest fall applications. In various trials at Agassiz high temperatures have resulted in more severe injury to grass.

Sodium arsenite applied on areas which had previously been treated with stove oil eradicated mouse ear chickweed with one application at full strength. In other areas where no previous spraying had been done full strength sprayings have given excellent control of this weed. Subsequent trials showed that for chickweed a solution made with $\frac{1}{2}$ ounce to a gallon of water was an effective and desirable way of controlling chickweed. In lawn areas where plantain, chickweed and pearlwort are present the recommended treatment is a spray of stove oil for plantain followed by one of sodium arsenite for chickweed and a spot application of iron sulphate for pearlwort. Small areas of Prunella and pearlwort have not been eradicated in single treatments. Yarrow in plots treated with four applications has made strong recovery.

At the Toronto Golf Club (8) fairways have been treated with sodium arsenite and arsenic pentoxide with highly satisfactory results in controlling dandelion, knotweed, clover, plantain and chickweed. As far as the writer knows, these are the most extensive trials carried out in Canada.

Mr. L. G. Klein of the Ontario Agricultural College in correspondence to the writer states that sodium arsenite is the most promising material tested at the College for large scale clean-ups. As an initial treatment, three spring and three fall treatments are necessary the first year, with a single spring and fall treatment in following years. This evidence is comparable to that obtained at the Toronto Golf Club. More evidence for

long term treatment is necessary. Rates of application have been 4 ounces of sodium arsenite to 30 gallons of water to 1,000 square feet, and 6 ounces for 1,000 square feet on sandy soils, these dilutions for use with power sprayers. Madden (13) recommends comparable amounts of material but lesser quantities of water, 5 gallons to approximately 1,000 square feet for hand spraying.

The evidence from a variety of sources points to the value of arsenicals, with as many as six sprays being required the first year. Control has been obtained for a wide variety of weeds, including crab grass. The subject cannot be dealt with at full length here and the references made above should be consulted. The 1940 trials at Agassiz were not encouraging for the control of dandelions and plantain. The weaker dilution mentioned offers an added possibility.

Meo 181

In Canada, Silversides and Olson (11) report highly satisfactory results from this material when used according to the manufacturers' instructions for controlling dandelions. They obtained a 95% kill of this weed. The Superintendent of the Saanichton Experimental Station reports in correspondence that it is the most promising chemical he has used, especially for weeds such as dandelions and others which exude latex on being cut. (Saanichton reports that arsenicals are too severe in burning.) This may be due to too dry soil. Limited trials at Agassiz in 1940 have resulted in very severe turf injury. The cost of this material makes its use on anything but a small scale or for spot treatments prohibitive.

Sinox

Results in California (12) are very promising for this material when used at a dilution of 1 to 20 for dandelions and 1 to 28 for plantain, applying 3 quarts to 100 square feet. Results at Agassiz come in the same category as that of Meo 181 and sodium arsenite, namely, that the material has value but that more work is necessary before it can be given a definite rating. Sinox at Agassiz has imparted a dark green colour to all grass plots treated. It has, as well, controlled worms to an appreciable extent. In various plots after treatment it was noted that a few dead worms appeared on the surface and that after a lapse of time comparatively few worm casts were present as compared to areas treated with other sprays. In order to arrive at a numerical conclusion duplicate areas 1 yard square were marked out on plots which had previously been treated with Sinox, sodium arsenite and stove oil. To each of these areas 2 gallons of lime sulphur, 1 to 200 dilution was applied and worms brought to the surface were counted. The following table gives the results obtained:—

Effect of Sinox in Controlling Worms

Plot 1— 1 sq. yd.	Sinox No. of worms	Sodium arsenite No. of worms	Stove oil No. of worms
Area 1	3	42	27
Area 2	5	41	52
Plot 2—			
Area 1	5	47	48
Area 2	1	58	39

The effect of Sinox is conclusive. The great majority of worms are killed in the ground which is the ideal way.

APPLICATION OF SPRAYS

All-over sprays are best applied with some form of spray pump. Under large scale conditions, power machines rigged with vegetable booms are the most satisfactory. For garden lawns, bucket pumps or knapsack sprayers are suitable. Where oil is used the pump should have leather rather than rubber washers. With a good spray pump 1 gallon of solution can be uniformly spread over 300 square feet. Before making a treatment it is first advisable to make a trial with 1 gallon of water to become acquainted with the approximate rate of coverage. The area to be treated with a given quantity of solution should be marked out with string, and long narrow strips can be treated more uniformly than square areas where the surface cannot be carefully watched. For an area of 200 square feet it is better to mark out a strip 5 feet × 40 feet than to mark out an area 10 feet × 20 feet. Oil sprays or sprays with a kerosene base such as Meo, or sprays with a basic dye material such as Sinox, leave a readily distinguishable mark as soon as the grass is wetted and make uniform coverage easier than with such solutions as copper sulphate and arsenicals. For these a cheap dye is desirable. Ponceau 3R is a suitable dye for this work, according to correspondence from the Division of Chemistry, Science Service, Ottawa, but does not meet the requirement of being cheap. For spot treatment of spreading weeds small hand sprayers with the solution container attached are convenient when they have a nozzle which permits of a downward spray when the pump is held in a horizontal position. For individual weeds such as plantain and dandelion, especially small seedlings, oil cans which work with a pump principle are desirable. The various spray materials used at Agassiz have all indicated that some burning of grass must result if there is to be satisfactory weed control. Where coverage has been poor and the grass not scorched weed control has not been satisfactory. Apart from considerations mentioned elsewhere, spray should only be applied when there is no wind. There is also likelihood of less danger from excessive heat if spraying is done in the late afternoon as compared to early morning.

In order to assure quicker recovery of grass from spray injury an application of sulphate of ammonia should be given a few days before spraying is undertaken. Fall sprays should be so timed that the grass will have a full opportunity of recovery before growth stops. The recovery period will vary according to the severity of burning and general growth conditions. Six weeks should, however, be provided for. Moss and weeds will invade areas which go into winter in an unthrifty condition. Crab grass will become troublesome when the turf is thin. A dense turf tends to keep out dandelions more than it does plantain.

In making provision for the complete care of a lawn, which includes such items as listed in the opening paragraph, the labour required will be

several times greater than that given to many turf areas. Applications of fertilizer necessitate more frequent cutting, removal of clippings takes care of many weed seeds and lowers weed population, spiking assists in water penetration, raking brings to the surface coarse grass, watering increases growth, top dressing levels the surface and assures a better rooting medium, worm control helps maintain a smooth surface, and spraying and hand digging of weeds remove the weed pest and so increase the vigour of the grass. All these are labour consuming operations which must be met if satisfactory results are to be obtained.

CONCLUSION

The above remarks on chemicals and turf operations leave much unsaid and refer only briefly to a few of the many publications and experiences which might be quoted. Weed control in turf must be considered from two angles, that of the small area around homes and that of large areas such as in golf courses, boulevards, public parks and athletic fields. Perfection in turf is most closely approached on golf greens and bowling lawns. Here the cost and amount of labour required to maintain such areas makes it prohibitive to have comparable results in home lawns and larger areas. One golf course superintendent has informed the writer that the hours of man labour in greens as compared to fairways is in the proportion of $4\frac{1}{2}$ to 1. There are few, if any, golf course superintendents who would undertake to maintain their own private lawns on a basis comparable to the greens which they supervise. A perfect lawn must be given every possible consideration.

Chemical weed control at Agassiz and elsewhere has proved practical both on small and on large areas. So far as the experience of the writer is concerned, he will continue to use stove oil on his private lawn for dandelion and plantain. If chickweed is present this should be treated with sodium arsenite, pearlwort with iron sulphate and catsear with copper sulphate. There is no doubt that there are others who are equally enthusiastic over different materials. The cost of material and the number of applications required are important considerations. In the interest of better sward it is hoped that future years will bring many new enthusiasts for one or more of the treatments recommended or for something still untried. There is abundant evidence to show that a preliminary failure with one or more materials should not act as a permanent discouragement. One hundred per cent control of weeds should not be expected either in a single spraying or in repeated sprayings. Some weeds will always escape—new seedlings will always appear. When the happy stage of a nearly weed-free lawn is attained, then the owner will be confronted with the problem as to whether he will dig out the occasional intruders by hand, whether he will treat weeds individually with an oil can or a small hand sprayer, or whether he will allow them to become sufficiently thick again to warrant an all-over spray. Wherever grass will grow we must expect some weeds, but there is abundant proof that the total population may, with some extra work and expense, be kept to the level where weeds are very scarce.

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INVESTIGATIONS ON THE THIAMIN CONTENT OF CANADIAN WHEAT AND FLOUR[1]

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The attention of nutritionists in Canada, Great Britain and the United States has recently been drawn to the fact that the average diet is deficient in vitamin B_1, or thiamin. The best work in the field of nutrition places the daily requirement of this vitamin at from 500 to 600 international units for each individual (5). Surveys in the United States show that the average daily intake is from 250 to 350 international units, while in Canada the average daily intake (in the low and middle income groups) ranges from less than 200 to 400 units per day (4). Wheat products constitute one of the greatest single sources of energy in the modern diet, and bread probably accounts for 25% of our daily caloric intake. The refinements introduced in the milling of wheat into white flour and the preference of the general public for white bread do not take advantage of the excellent store of thiamin in the whole wheat. Hence programs to alleviate the above mentioned condition by increasing the thiamin in flour are being implemented in Great Britain and in the United States, and these programs are having their repercussions in Canada. A knowledge of the amount of thiamin already present in the wheat and flour produced in this country is necessary to the satisfactory formulation of a plan for Canada. A survey of the thiamin content of the commoner varieties of wheat grown in Canada, and of the flours milled from this wheat was undertaken accordingly, and data obtained to date are presented in this paper.

In conjunction with this survey, experiments directed toward increasing the thiamin content of flour by variation of the present milling practice were also conducted. The co-operation of The T. H. Taylor Company, Ltd., of Chatham, placed these experiments on a commercial footing and, as a direct result, two types of high vitamin flour are now being marketed. The first of these flours contains 400 to 500 i.u. of thiamin per pound, and bakes into a loaf of good volume and texture, but dark in crumb colour. The second variety is distinctly lighter in colour and more closely approaches the standard white flour, but contains about 10 to 15% less thiamin than the first.

Prior to the inception of this research program, the thiochrome method of analysis for thiamin had been established in the Department of Paediatrics, and all thiamin determinations were made in this laboratory. At the beginning of the survey the procedure was essentially that of the original method of Cerecedo and Hennessy (3). As the work progressed changes were introduced designed to simplify the method without reducing its accuracy. No change was made until exhaustive tests showed that there was no detrimental result. Thus all analyses shown are comparable, no matter what particular modification of the analytical procedure was in

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use at the time. The latest method of analysis, with which about half the results were obtained, is that recommended by the Research Corporation Committee on the Thiochrome Method (6), and incorporates the modifications recently published by Hennessy (2). Tests with this method show an over-all recovery of added thiamin of 90% to 103%, with an average recovery of 97.7%. Duplicates to within 8% are consistently obtained.

The method, in its various stages of modification, was repeatedly checked against bioassays, using the rat growth technique. The materials so checked were wheat, whole wheat flour, high extraction flour, bread and Pablum. In every case checks were obtained well within the limit of error of the bioassay. Figure 1 gives the composite curves obtained from all these tests. The broken line is the growth curve of a group of rats on a basal diet devoid of thiamin supplemented daily with an amount of the material being tested that was found, by the chemical analysis, to contain 1 unit of thiamin. Each point on this curve is the average weight of 114 rats. The solid line is the growth curve of a similar group of rats, matched as to litter and sex, in which the basal diet was supplemented by the daily addition of 1 unit of pure crystalline thiamin. Each point on this curve is the average weight of 96 rats. That the rate of growth of each group of rats is identical is indication that the chemical method of assay determines the true thiamin content accurately.

The survey divided itself broadly into three main sections: First, the amount of thiamin in the wheat at present obtainable commercially, and in the various varieties of wheat commonly grown. In this section is

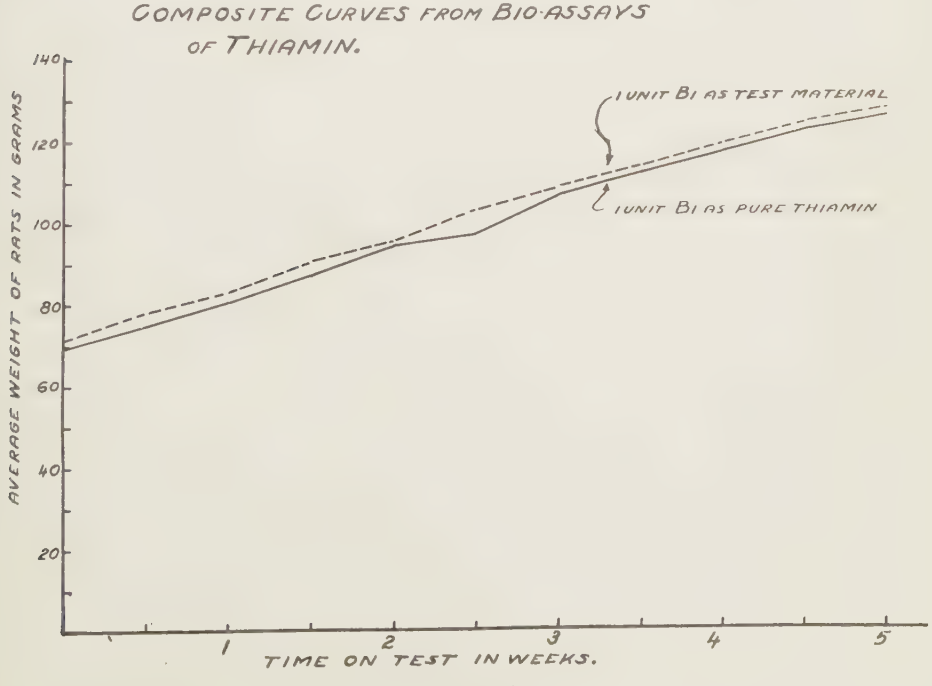

FIGURE 1

included some research designed to locate the sites of the thiamin in the wheat berry. Second, an investigation was made of the amount of thiamin in bakers' flour sold throughout Canada. This included analyses of the various mill-streams in two large modern flour mills with the hope that this information may be of service to millers in indicating changes that might be made to increase the vitamin content of their flours. In the third section are recorded the results of some experiments to illustrate the effect of tempering the wheat, prior to milling, and flour extraction on the thiamin content of the flour produced.

THE THIAMIN CONTENT OF CANADIAN WHEAT

Tables 1, 2, 3, and 4 record the amount of thiamin in wheat. All results are in international units of thiamin per pound of material. One international unit was taken as equal to 3 micrograms of thiamin. Table 1 shows the amount of thiamin in samples of hard wheat obtained from various mills. These samples were blends of the grades of wheat as mixed at the mills ready for grinding. The maximum range was from 537 i.u. per pound to 735 i.u. per pound, but the largest majority of the samples were very close to 650 i.u. per pound.

TABLE 1.—THIAMIN CONTENT OF COMMERCIAL HARD WHEAT SAMPLES AS MILLED

Mill	Thiamin per lb.
	i.u.
Western Canada Flour Mills Co., Ltd.	565
Lakeside Milling Co., Ltd.	537
Ogilvie Flour Mills Co., Ltd.	655
Ogilvie Flour Mills Co., Ltd.	630
Maple Leaf Milling Co., Ltd.	680
The T. H. Taylor Company, Ltd.	655
The T. H. Taylor Company, Ltd.	625
The T. H. Taylor Company, Ltd.	630
The T. H. Taylor Company, Ltd.	638
The T. H. Taylor Company, Ltd.	623
The T. H. Taylor Company, Ltd.	610
The T. H. Taylor Company, Ltd.	675
The T. H. Taylor Company, Ltd.	655
Quaker Oats Company	735

To obtain further information on the thiamin content of Canadian wheat, samples representing different cargo shipments collected by the Chief Grain Inspector during the crop year 1940 and 1941 out of shipments from Fort William and Vancouver, were assayed. Each sample represented a cargo of 18,000 to 509,000 bushels and all samples were taken at random over a period from September to December 1940 at Fort William and up to February 1941 at Vancouver. While the data from these samples would not give much information on the variation to be expected in small parcels of wheat, they tend to show the general average for the wheat produced in Western Canada as a whole during 1940 and possibly previous crop years. In Table 2 the maximum, minimum and mean thiamin contents for the

cargoes falling into each grade are recorded. From these data it would appear that the thiamin content bears little relationship to the grade of wheat, but the shipments through Vancouver ran lower, particularly in Manitoba 3 northern, than corresponding grades shipped through Fort William. The Garnet grades were lower than were the northern grades.

TABLE 2.—THIAMIN CONTENT OF CARGOES OF CANADIAN WHEAT

Type	Number of shipments	Thiamin per lb.		
		Mean	Minimum	Maximum
		i.u.	i.u.	i.u.
Manitoba 1 Northern ex. Fort William	10	650	614	721
Manitoba 2 Northern ex. Fort William	10	685	635	747
Manitoba 3 Northern ex. Fort William	10	667	610	728
Manitoba 4 Northern ex. Fort William	10	641	580	695
Manitoba 1 Northern ex. Vancouver	10	644	605	710
Manitoba 2 Northern ex. Vancouver	7	632	555	700
Manitoba 3 Northern ex. Vancouver	5	576	525	611
No. 1 C.W. Garnet ex Fort William	5	554	545	562
No. 2 C.W. Garnet ex Fort William	6	553	534	563

Table 3 lists the amount of thiamin in some of the common varieties of hard wheat grown in Canada in 1939. The samples were collected from 158 elevator points throughout the three Prairie Provinces and thoroughly mixed prior to analysis. Thus these results are a good average figure for each variety. Regent and Renown are outstanding for their high vitamin content, and are followed by Reward. Thatcher, Apex and Marquis gave relatively lower values in these comparisons.

TABLE 3.—VARIETIES OF HARD WHEAT—COMPOSITE SAMPLES* 1939 CROP

Variety	Thiamin per lb.	Variety	Thiamin per lb.
	i.u.		i.u.
Apex	670	Renown	820
Marquis	645	Reward	806
Regent	820	Thatcher	700

* Samples collected at 158 elevator points and mixed. Assays on the mixed samples.

Table 4 records the amounts of thiamin in different varieties of wheat collected at widely separated points in the Canadian West. This was intended to show up the possible effect of location on the thiamin content of the wheat. However, the variations are not sufficiently consistent to lead to any very definite conclusions. Melfort was the poorest location for Garnet, Red Bobs, Reward and Marquis, but it was the best for Regent, and nearly the best for Thatcher. All samples were high in test weight per bushel except those from Olds, Alberta, and they were over 61 lbs. These data lend further support to the results given in Table 3 that there is a difference between varieties in thiamin content.

TABLE 4.—VARIETIES OF HARD WHEAT—ASSAYS ON SAMPLES FROM VARIOUS LOCATIONS 1940 CROP

Variety	Grown at	Test weight per bushel	Thiamin per lb.	
			Individual sample	Variety mean
		lb.	i.u.	i.u.
Garnet	Rosthern	63.5	535	
Garnet	Olds	61.5	565	
Garnet	Scott	64.0	585	545
Garnet	Melfort	64.5	517	
Garnet	Edmonton	66.5	525	
Red Bobs	Rosthern	64.0	700	
Red Bobs	Olds	61.0	785	
Red Bobs	Scott	64.5	695	697
Red Bobs	Melfort	64.5	631	
Red Bobs	Edmonton	66.5	675	
Reward	Rosthern	64.5	840	
Reward	Olds	62.5	765	
Reward	Scott	66.0	840	774
Reward	Melfort	66.0	711	
Reward	Edmonton	67.5	712	
Marquis	Rosthern	63.5	715	
Marquis	Olds	61.0	687	
Marquis	Scott	64.5	665	663
Marquis	Melfort	65.5	610	
Marquis	Edmonton	65.5	640	
Regent	Rosthern	63.5	806	
Regent	Olds	62.0	735	
Regent	Scott	64.0	870	809
Regent	Melfort	64.0	870	
Regent	Edmonton	66 0	765	
Thatcher	Rosthern	63.5	690	
Thatcher	Olds	61.5	615	
Thatcher	Scott	64.0	611	641
Thatcher	Melfort	64.0	660	
Thatcher	Edmonton	65.5	630	

Table 5 shows the amount of thiamin in a few samples of soft wheat. The data, here, are too meagre for any conclusions to be drawn.

TABLE 5.—VARIETIES OF SOFT WHEAT, SINGLE SAMPLES—GROWN IN ONTARIO

Variety	Thiamin per lb.
	i.u.
Dawson's Golden Chaff	622
Junior No. 6	675
Nigger	623
Ontario winter wheat (Maple Leaf Mill mix)	567

As shown later (Table 9) the bran, shorts and wheat middlings contain much higher quantities of thiamin than the white flours produced in the milling of wheat. It is, therefore, logical to conclude that the thiamin is more highly concentrated in those parts of the kernel other than the floury endosperm. A sample of commercial Manitoba 1 Northern was used to

obtain further information regarding the location of the vitamin in the wheat kernel. The germ proper was probed out of a large number of kernels. Other wheat kernels were cut crosswise in approximately three equal parts, and each section was analysed separately. In Table 6 it will be observed that the wheat germ showed the highest concentration, but it can readily be calculated that this part of the kernel contributed only a small proportion to the total thiamin. The germ end of the kernel representing approximately one-third by weight showed a much higher concentration of thiamin than the other two-thirds. It would appear that those cells immediately surrounding the germ contribute substantially to the total thiamin in the wheat kernel.

TABLE 6.—CONCENTRATION OF THIAMIN IN DIFFERENT PARTS OF THE WHEAT KERNEL

Kernel section	Percentage by weight	Thiamin per lb.
	%	i.u.
Brush end	33.9	222
Centre section	33.9	158
Germ end—germ intact	32.2	1,700
Germ proper	1.47	3,300

THE THIAMIN CONTENT OF CANADIAN FLOURS

The results of investigations into the amounts of thiamin to be found in various types of flour are recorded in Tables 7 to 10. In Table 7 the thiamin contents of the main types of flour, as milled by a large company, are listed. As is to be expected, whole wheat flour contains the same amount of thiamin as the wheat from which it is milled. Corresponding grades of bread flour and pastry flour appear to contain about the same amount of the vitamin, the first grade flour in each case containing less vitamin than the lower grades. The high extraction flour being milled by the T. H. Taylor Company, Limited, varies between 400 to 500 international units per pound on different runs.

TABLE 7.—COMMERCIAL TYPES OF FLOUR

Type of flour	Thiamin per lb.	Thiamin of corresponding wheat per lb.
	i.u.	i.u.
Whole wheat	657	666 (at 13% H_2O)
Bakers' straight	185	666
Bakers' patent	140	666
Pastry straight	185	567
Pastry fancy	122	567
Durum Semolina (macaroni)	163	711
Durum flour (macaroni)	181	711
High extraction	400-500	625-700

A large series of samples of bakers' patent flours milled by concerns scattered throughout the country were collected and analysed, and these results are contained in Table 8. The majority of the flours are second patents, but one first patent and one third patent are included. The value obtained for "U" "Family Patent" of 244 i.u. per pound is outstandingly high. The average value of all the flours recorded is 160 i.u. per pound. Calcu-

TABLE 8.—THIAMIN CONTENT OF BAKERS' FLOUR FROM CANADIAN MILLS

Milling company	Grade of flour	Thiamin per lb.	Milling company	Grade of flour	Thiamin per lb.
		i.u.			i.u.
A	Bakers' patent	163	L	Second patent	194
B	Second patent	167	M	Second patent	138
C	Second patent	132	N	First patent	80
D	Second patent	148	O	Second patent	163
E	Second patent	138	P	First clear	147
F	Third patent	198	Q	Straight	152
G	Second patent	175	R	Second patent	171
H	Second patent	115	S	Second patent	175
I	Second patent	120	T	Bakers' patent	189
J	Second patent	163	U	Family patent	244
K	Bakers' patent	179			

TABLE 9.—THIAMIN CONTENT OF FLOUR STREAMS PRODUCED IN MILL X

Stream	Percentage of total flour	Thiamin per lb.
	%	i.u.
1st Break	0.50	106
2nd Break	0.50	102
3rd Break	0.50	124
4th Break	0.50	184
5th Break	0.50	375
Break sifts	3.00	119
1st Middlings	15.00	61
2nd Middlings	13.00	128
2nd Middlings Rebolt	5.00	159
3rd Middlings	11.00	159
3rd Middlings Rebolt	3.00	159
4th Middlings	9.00	127
4th Middlings Rebolt	3.00	177
5th Middlings	7.00	157
5th Middlings Rebolt	4.00	179
6th Middlings	6.00	211
6th Middlings Rebolt	4.00	244
Sizings	3.00	128
1st Low Grade Bolted	1.75	344
1st Low Grade Rebolt	1.50	410
2nd Low Grade Reels	1.75	576
Fine Tails	1.00	303
1st Tails	1.00	406
2nd Tails	0.75	615
1-2-3 Middlings Scalp Reel	0.50	245
4-5 Middlings Scalp Reel	0.50	295
B. & S. Duster Reels	1.00	735
B. & S. Duster Bolter	1.00	605
Red Dog Reels	0.75	1,115

lated on the basis of a 72% extraction flour milled from wheat containing an average of 650 i.u. per pound, the average Canadian bakers' flour accounts for only 18% of the vitamin B_1 in the wheat. This corresponds to the recovery reported by Frey, Schultz and Atkin for American flours (1). The low value of 80 i.u. per pound was obtained on a first patent flour.

Tables 9 and 10 give the amount of thiamin in the individual mill-streams of two large Canadian mills. In general, as the milling process advances the concentration of thiamin in the various flour streams increases, and those streams contributing to the greatest proportion of the total flour have the lowest unit quantities of thiamin. The very large amounts of thiamin shown for the bran, shorts and wheat middlings, given at the end of Table 10, are noteworthy.

TABLE 10.—THIAMIN CONTENT OF FLOUR STREAMS PRODUCED IN MILL Y

Stream	Percentage of total flour	Thiamin per lb.
	%	i.u.
1st Break	0.50	117
2nd Break	0.50	97
3rd Break	0.50	101
4th Break	0.50	190
5th Break	0.50	570
Break Cuts	1.00	97.5
1st Middlings	15.00	64.3
2nd Middlings	16.00	33
3rd Middlings	13.00	62
4th Middlings	10.00	74
5th Middlings	7.00	121
6th Middlings	7.00	141
7th Middlings	5.00	231
8th Middlings	4.00	246
9th Middlings	3.00	356
10th Middlings	2.00	545
Middlings Dust	1.25	122
1st Sizings	1.00	118
2nd Sizings	1.25	93
3rd Sizings	1.00	426
1st Tailings	1.75	326
2nd Tailings	1.00	172
3 B1 Flour	1.75	183
3 B2 Flour	2.00	112
Suction Flour	1.00	111
Low Grade Flour	1.00	855
Bran and Shorts Dust Flour	1.50	635
Feeds		
Bran	50.00	1,440
Shorts	40.00	2,710
Wheat Middlings	10.00	2,280

EXPERIMENTAL MILLING TESTS TO INCREASE THE THIAMIN CONTENT OF WHITE FLOUR

The foregoing data on the thiamin content of bakers' flour and of the various flour streams in two large modern flour mills would lead one to conclude that some changes would have to be made somewhere in the procedure if substantial quantities of high vitamin flours were to be pro-

duced. It is obvious that most of the thiamin is concentrated in the feed products and in some of the darker flour streams, and those flour streams found in the greatest percentages contain the lowest unit quantities of thiamin. The T. H. Taylor Co., mentioned at the beginning of this paper, had been experimenting with the manufacture of high vitamin B_1 flour. They produced a relatively dark flour milled from wheat going to the rolls at a moisture content about 13.0% and which was the result of carrying the extraction to 82% or 83%. One of these flours, which assayed 525 i.u. of thiamin per lb., was bolted through a 10XX silk flour sieve, thus removing about 10% of coarse material. The rebolted flour assayed 421 i.u. of thiamin per lb. and the bread baked from it approached a white loaf. This led to a series of experiments in which wheat was milled experimentally at different moisture contents producing a straight grade flour in each case.

In Table 11 are recorded data on the milling of a sample of Manitoba 1 Northern wheat with a moisture content of 10.8% and a thiamin content of 655 i.u. per lb. The wheat was tempered to two moisture levels[1], namely, 12.5% and 15.5%, and for each milling 1,730 gms. on a dry matter basis were weighed out. The milling was done in a Buhler mill with varying procedures in order to vary the flour extraction percentages. All flour passed through 10XX flour silk sieves. The flour yields were computed on the basis of flour obtained to wheat milled (actual) and on the basis of wheat milled minus the feed products (by difference). (There is always a loss, chiefly flour, in the milling of small samples and therefore, the calculation "by difference" may approach more closely to the yield expected from large samples.) It will be observed that higher flour extractions were obtained by milling at 12.5% moisture than at 15.5% and this was accompanied by higher ash flours and flours higher in thiamin content. In both series, as extraction increased the ash and thiamin content increased.

TABLE 11.—INFLUENCE OF TEMPERING ON THE THIAMIN CONTENT OF EXPERIMENTALLY MILLED FLOURS FOR A SAMPLE OF MANITOBA 1° WHEAT MILLED AT 2 DIFFERENT MOISTURE LEVELS. ORIGINAL MOISTURE OF WHEAT 10.8%. WHEAT MILLED ON BASIS OF 1,730 GMS. DRY MATTER PER SAMPLE. THIAMIN CONTENT OF WHEAT 655 I.U. PER POUND

Moisture of wheat at rolls	Milling time	Flour yield		Flour ash	Thiamin per lb. of flour
		Actual	By diff.		
%	Min.	%	%	%	i.u.
12.5	22	74.7	76.2	.54	365
	22	72.4	74.4	.62	353
	34	74.6	77.2	.61	411
	34	75.1	77.4	.65	437
	44	74.9	78.6	.71	479
	45	76.9	78.6	.71	506
15.5	22	73.4	74.8	—	254
	22	71.6	73.9	.51	229
	34	69.8	73.6	.53	292
	33	73.3	75.7	.53	300
	45	72.1	75.5	.59	298
	42	71.4	75.3	.59	299

[1] All moistures recorded in this paper were obtained by the air oven method (130° C. for one hour). For wheat the values would be about 0.4% lower than by the Brown-Duvel moisture tester.

In Table 12 the influence of percentage extraction on the ash and thiamin content is shown for two samples of wheat. It is interesting to note that tempering wheat to the higher moisture level of 15.5% produced flours of high thiamin content when the extraction was extended.

TABLE 12.—INFLUENCE OF FLOUR YIELD ON THIAMIN CONTENT

Wheat sample	Moisture of wheat at rolls	*Flour yield		Flour ash	Thiamin per lb. of flour	Flour yield†		Flour ash	Thiamin per lb. of flour
		Actual	By diff.			Actual	By diff.		
	%	%	%	%	i.u.	%	%	%	i.u.
Regent	12.5	66.4	75.1	.42	223	75.1	78.2	.53	415
(original moisture	13.5	68.6	72.8	.42	193	74.1	78.3	.48	366
10.2%)	14.5	68.6	71.8	.40	—	73.2	78.1	.50	356
	15.5	67.5	72.0	.39	140	74.5	78.2	.47	350
Man. 2c	12.5	69.6	72.7	.47	217	72.6	78.2	.55	435
(original moisture	13.5	65.4	69.6	.45	205	74.7	77.4	.53	410
10.0%)	14.5	65.7	69.6	.44	166	72.3	77.3	.53	354
	15.5	66.2	69.2	.41	141	74.0	76.6	.50	352

* Wheat milled on basis of 1,730 gms. dry matter per sample.
† Wheat milled on basis of 865 gms. dry matter per sample.

In Table 13 data for the milling of small samples from three commercial wheat mixes supplied by three milling companies in Eastern Canada from wheat being used currently in these mills during April, 1941, are presented. All of these samples were milled in the same manner except that the moisture of the tempered wheat was varied. Here again the importance of extraction on the thiamin content is indicated. Milling wheat at the lower moisture contents allowed for an increase in extraction which resulted in a corresponding increase in thiamin content and ash content.

TABLE 13.—THIAMIN CONTENT OF EXPERIMENTALLY MILLED FLOURS FROM 3 COMMERCIAL MILL WHEAT MIXES

Origin of wheat sample	Weight per bushel	Original moisture of wheat	Moisture of wheat to rolls	Flour yields		Flour ash	Thiamin per lb.	
				Actual	By diff.		Wheat	Flour
	lb.	%	%	%	%	%	i.u.	i.u.
Mill A	64.4	12.0	12.5	73.2	77.6	.59	680	378
			13.5	72.7	78.2	.59		382
			14.5	71.9	76.6	.58		335
			15.5	71.0	75.6	.54		295
Mill B	62.5	12.1	12.5	71.2	76.7	.58	735	412
			13.5	70.1	77.6	.57		350
			14.5	70.0	76.1	.54		301
			15.5	71.1	76.0	.54		292
Mill C	63.5	10.8	12.5	75.9	78.1	.59	630	412
			13.5	76.4	77.8	.56		420
			14.5	70.0	74.9	.49		244
			15.5	69.7	72.5	.50		195

In another experiment larger milling samples were employed to reduce losses which occur in milling small samples and the data are presented in Table 14. Milling wheat at the lower moisture levels increased the thiamin

content even though flour extraction remained approximately the same for all samples. From the foregoing experiments it would appear that higher vitamin white flours may be produced by either milling wheat at a lower moisture level than is the usual practice or by increasing the extraction. In commercial practice wheat is usually sent to the rolls at 15.5% to 16.0% moisture, and extraction carried to 72 to 75%.

TABLE 14.—THE EFFECT OF WHEAT MOISTURE ON THE THIAMIN CONTENT OF FLOUR FROM THE EXPERIMENTAL MILLING OF LARGE SAMPLES OF WHEAT. MILLING YIELD DATA CALCULATED ON ORIGINAL WEIGHT OF WHEAT SAMPLE

Moisture of wheat to rolls	Bran	Shorts	Flour	Gain or loss	Flour		
					Moisture	Ash	Thiamin
%	%	%	%	%	%	%	i.u. per lb.
45 lb. wheat samples—original moisture 11.8%—weight per bushel 63.5 lbs.							
13.0	18.3	8.0	72.7	−1.0	12.5	.53	339
14.0	20.0	7.3	72.8	0.1	13.0	.48	262
15.5	22.4	5.6	73.0	1.0	13.7	.40	183
30 lb. wheat samples—original moisture 13.4%—weight per bushel 62.9 lbs.							
13.4	19.2	5.9	73.1	−1.8	13.1	.53	290
14.0	19.0	5.3	73.2	−2.5	13.0	.53	284
15.5	21.7	3.3	73.8	−1.2	13.5	.50	252

SUMMARY

Analyses of the thiamin (vitamin B_1) in samples of Canadian wheat and flour are given.

Commercial samples of wheat at the mill averaged about 650 i.u. per pound. Corresponding values were obtained for cargo shipments representing the various contract grades. While there were variations of more than 100 i.u. per pound between samples within the grades, there is little relationship between grades. The Manitoba 3 Northern ex Vancouver and the 1 and 2 C.W. Garnet ex Fort William grades were lower than the other grades.

Of the varieties grown commercially in Canada, Regent and Renown wheat contained the greatest quantity of thiamin. Garnet contained the least, while Thatcher, Apex and Marquis were not as high as the first two mentioned varieties in comparisons made thus far.

The thiamin is concentrated in the wheat berry largely at the germ end of the kernel and in the germ proper. The germ itself, representing only a small percentage of the whole kernel, is not the main contributor to the thiamin content of the whole kernel. Those cells immediately surrounding the germ must also contribute substantially.

The thiamin content of bakers' patent flours milled in Canada averages about 160 i.u. per pound, the fancy grades containing less and the lower grades more.

Analyses of mill-streams show a general progressive increase in the thiamin concentration in the individual flour streams as the wheat advances through the milling process. The concentration in the bran, shorts and feed middlings is very high.

Data from certain experimental milling tests designed to increase the thiamin content in white flour are presented. The thiamin content was increased by milling wheat below 15.5% moisture going to the rolls, and by increasing extraction. These flours were less refined than those produced by milling at the orthodox moisture and extraction percentages.

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THE RELATIVE EFFECT OF ENVIRONMENT AND HEREDITY UPON BODY MEASUREMENTS AND PRODUCTION CHARACTERISTICS IN POULTRY[1]

I. PERIOD OF GROWTH

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The factors which influence such characters as body size, muscular development, and egg production in fowl are either hereditary or environmental in nature. The difficulty of estimating the comparative contribution of heredity and environment to any biological characteristic is generally well appreciated. At the same time a lack of appreciation of the comparative effect which each exerts has, in the past, without doubt contributed to some confusion as to which has made the greatest contribution in any specific instance.

For example, many operators of poultry breeding enterprises have built up a reputation for high quality breeding stock on the basis of the high egg production records which they obtained. The possibility that these records may have been due largely to environmental factors such as suitability of climate, availability of high quality feeds, and the efficient management of the operators themselves rather than to breeding worth of the birds, was usually overlooked. Similarly, stock has been sold on the basis of reputed high market quality as well as production potentialities, again without considering that environmental factors may have largely contributed to their market quality rather than inherent qualities of the strain.

Considering egg production, it has been maintained by Petrov (6) and Munro (3, 4, 5) that improvement during the last few decades has been largely due to improvement in environment rather than to breeding. Through the analysis of pertinent data Munro (*loc. cit.*) with egg production, Plum (7) with butter fat production in cattle, and Bywaters (1) with weaning weight in pigs made strikingly similar estimates of the relative effects of genetic and non-genetic influences and reported environment to have a much greater effect than heredity on expression of these characters.

Additional information upon this problem was sought through an experiment in which several strains of birds were kept under the same environment, and the same strains under different environments, from the incubator to the end of a laying year in order to obtain information concerning environmental and hereditary effects on growth and body conformation of cockerels as well as egg production of pullets.

In order to gain these ends it was necessary to choose several different flocks of one breed, each of which had been bred at one location for a sufficient number of years to have developed the individual characteristics of a strain and to have these strains carried at several locations, each of which had, if possible, quite different environmental conditions of climate,

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management, feeds and other factors. It was also essential to be able to carry a sufficient number of birds of each strain at each location to make the sample large enough to be representative of the strain as determined by biometrical requirements. The Branch Farms and Stations of the Experimental Farms Service were found to be highly satisfactory for this purpose and an experiment was therefore set up covering three of these institutions. The experiment here reported was planned on this basis and covered a period from March 1937 to September 1938.

MATERIALS AND METHODS

The breed used in these experiments was the Barred Plymouth Rock. Three locations were chosen and are designated herein as locations A, B and C. These locations are characterized by quite marked differences in characteristics of stock and conditions of environment. From the standpoint of stock, that at location A has been bred for many successive generations under the more or less isolated conditions of a district somewhat difficult of access with only a relatively small amount of importation of sires over a period of some years; that at location B came in 1932 from chicks some of which originated at location C and some from an Experimental Station in northern Quebec; that at C has been bred for many years at that location with occasional importations from different sources over a period of years. That these flocks possessed individual well marked characteristics became evident during the progress of the experiment in that it was easily possible on the basis of colour and type to pick out the cockerels of each strain as they ran together on the range. While these flocks were not as completely unrelated as might be wished, at the same time they are fairly typical of breeders' flocks throughout the country where blood from many sources is introduced into the flock from time to time. From the standpoint of environment, the climate at location A is humid and moderately severe in winter with cool summers; that at location B is very temperate being warm in summer and mild in winter; that at location C is very cold in winter and also very hot in summer. All things considered the three climates might be considered as relatively mild at location B, moderate at location A, and severe at location C.

Numerous other environmental factors such as management, quality of feeds, type of housing and disease vary somewhat between locations and are not capable of being appraised in so far as their individual effects are concerned. For that reason the term environment in this work refers to all characters which are not inherent in the strain and which are covered by numerous factors some of which are mentioned above. It should be noted that all environmental factors are to a large extent under the control of the operator, even to the climate through suitable housing; hence improvements are quickly and readily made in contrast to the difficulty in making improvement in the complex hereditary factors such as egg production by breeding methods.

In order to obtain the greatest possible measure of control over both heredity and environment it was decided to maintain stock from each of the three strains at each location, thus making any differences between

the strains at any one location due, within the errors of sampling, to the heredity of the strain, while any differences between the same strain at the three locations would be due to environment.

To obviate the possibility of disease transfer, hatching eggs rather than live birds were exchanged between locations. Since the stock from which the eggs came was pullorum tested it was presumed that disease would not be transferred through the medium of the egg although the possibility of transmission of one disease, leucosis, by this means could not be entirely eliminated from consideration. The exchange was successfully made with the result that four hatches, one week apart, were made for each location comprising a population sufficiently large to give approximately 100 pullets in the laying houses and an adequate number of cockerels for growth and body measurements. It was considered to be very important that the populations at each location be representative of the strain, and all stock concerned, therefore, came largely from regular breeding pens and from as large a number of these as possible. Further, the eggs from each dam were divided as equally as possible between those retained at home and those sent to each of the two other locations. As a result there were relatively few instances in which full brothers or sisters were not found at each location.

One of the most important considerations was the establishment of identity of environment for the stock of all three strains at each location. This was accomplished by brooding chicks of the three strains intermingled in the same brooder and rearing houses from time of hatch to maturity thus making treatment identical in all respects. This principle was also put into effect in the laying house for the pullets. Almost identical environment was thus achieved for all three strains and any differences over and above normal error which were found between strains at any one location could rightly be considered to be due, with the exception of any pathological condition which might be passed through the egg, to inherent traits of the birds themselves. Similarly any differences between the performance of any one strain at the three different locations would be due to location, i.e., to environment.

The data are divided into two periods, namely, growth and egg production. The former only will be considered in this paper.

PERIOD OF GROWTH

These data were taken on live cockerels only and comprised weights at four weekly intervals from hatch to 24 weeks of age, and measurements of the breast angle, length of keel, height of keel, length of tibia, length of femur, and circumference of tibia at 16 and 24 weeks of age. The measurements cited may be considered as indicative of size and muscular development and in line with data required to determine rate of growth and market qualities.

The measurements of length were taken with outside calipers and read to the nearest millimeter from a steel tape. Circumference of tibia was measured by a steel tape at the largest girth of the tibia. Breast angle was measured by a special instrument consisting of steel bands adjustable

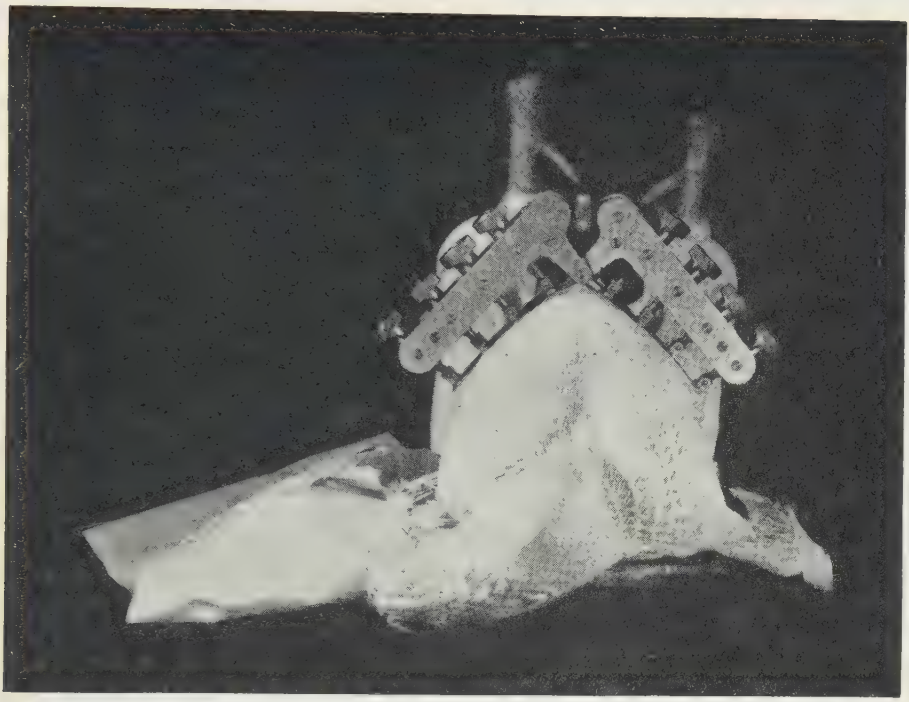

FIGURE 1. Measurement of breast angle.

by screws and capable of being closely fitted to the flesh of the breast. An illustration of the use of this instrument is shown in Figure 1. Plucking at the site of measurement was necessary to obtain an exact fit.

The measurement, height of keel was the distance between the anterior end of the coracoid bone and the point of keel.

All data obtained were analyzed statistically by the methods of variance and covariance, the experiment having been planned to that end. During the period of growth it was found that all hatches could be combined as one unit in the variance analysis since very few significant differences in any measurements occurred between hatches and then only during the first few weeks. Preliminary analyses also indicated that no significant differences occurred between the progeny of different dams and that the progeny of all dams could be considered as one population. Further analyses, however, indicated that a definite and significant difference existed between the progeny of different sires, and it was deemed expedient to base the variance analysis upon the mean value for the progeny of each sire.

RESULTS

The results obtained will be dealt with under the headings of "growth" and "body measurements".

GROWTH

The mean weights for each group appear in Tables 1 and 2. Any differences occurring between means in Table 1 are due, within the limits

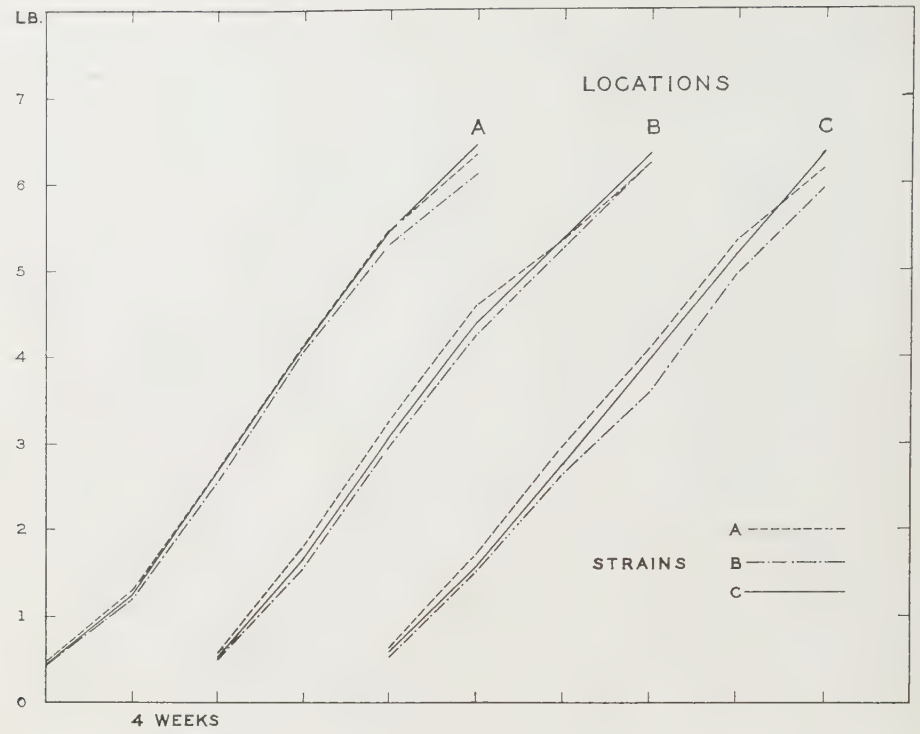

FIGURE 2. Influence of inheritance on growth.

of error, to strain or hereditary influences. Similarly those in Table 2 are due only to environment. Figures 2 and 3 are similarly arranged and the course of growth can be more easily followed through these growth curves. It is readily apparent from the greater spread of the curves that environment (Figure 3) had a considerably greater effect upon the course of growth than did inheritance (Figure 2). Strain A (Figure 2) showed a tendency towards more rapid growth, strains C and B being next in this respect in the order named. The data are consistent under the three environments, a fact which tends to increase confidence in the results obtained. After 20 weeks the birds of strain C began to show the greater ultimate body weight which they eventually attained.

TABLE 1.—MEAN BODY WEIGHTS OF COCKERELS—DIFFERENCES DUE TO STRAIN (HEREDITY)

	4 wks.	8 wks.	12 wks.	16 wks.	20 wks.	24 wks.
Location A—Strain A	0.499	1.28	2.65	4.14	5.45	6.32
Location A—Strain B	0.464	1.20	2.51	4.06	5.29	6.08
Location A—Strain C	0.485	1.24	2.66	4.11	5.44	6.42
Location B—Strain A	0.566	1.79	3.24	4.55	5.35	6.22
Location B—Strain B	0.494	1.53	2.96	4.25	5.26	6.21
Location B—Strain C	0.517	1.64	3.06	4.37	5.33	6.41
Location C—Strain A	0.615	1.68	2.93	4.09	5.33	6.18
Location C—Strain B	0.517	1.49	2.63	3.59	4.93	5.92
Location C—Strain C	0.583	1.55	2.74	3.96	5.18	6.44

TABLE 2.—MEAN BODY WEIGHTS OF COCKERELS—DIFFERENCES DUE TO LOCATION (ENVIRONMENT)

	4 wks.	8 wks.	12 wks.	16 wks.	20 wks.	24 wks.
Strain A—Location A	0.499	1.28	2.65	4.14	5.45	6.32
Strain A—Location B	0.566	1.79	3.24	4.55	5.35	6.22
Strain A—Location C	0.615	1.68	2.93	4.09	5.33	6.18
Strain B—Location A	0.464	1.20	2.51	4.06	5.29	6.08
Strain B—Location B	0.494	1.53	2.96	4.25	5.26	6.21
Strain B—Location C	0.517	1.49	2.63	3.59	4.93	5.92
Strain C—Location A	0.485	1.24	2.66	4.11	5.44	6.42
Strain C—Location B	0.517	1.64	3.06	4.37	5.33	6.41
Strain C—Location C	0.583	1.55	2.74	3.96	5.18	6.44

Environmental differences, as indicated in Figure 3, are apparent as early as four weeks of age and persist in some instances up to 24 weeks. These differences are not only significant but of considerable practical importance, ranging up to 17%. The environment of location B is definitely more favourable for production of rapid growth than either of the other locations. Of the latter, location C is the more favourable for early growth or to approximately 12 weeks of age, while from that point on, location A is more favourable and eventually practically equal to B. Attention is again drawn to the consistency of these data.

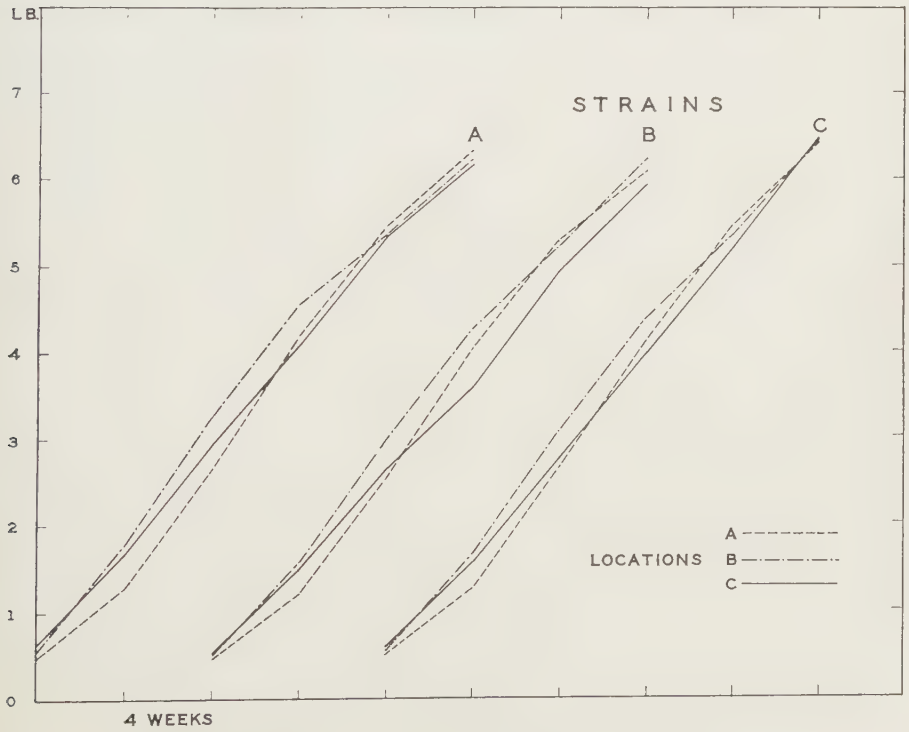

FIGURE 3. Influence of environment on growth.

In Tables 3 and 4 will be seen the variance analyses for all the characters under consideration for 16 and 24 weeks of age respectively. Considering the variance of growth both origin and location have a highly significant effect at 16 weeks of age. At 24 weeks, on the other hand, a significant effect of origin is indicated while location has had no significant effect.

TABLE 3.—ANALYSIS OF VARIANCE OF BODY MEASUREMENTS AT 16 WEEKS OF AGE

	Between locations Mean Square (D/F = 2)	F*	Between origins Mean Square (D/F = 2)	F*	Error Mean Square (D/F = 85)
Growth	1.98	18.00	0.79	7.18	0.11
Breast angle	545.68	43.45	11.48	–	12.50
Circumference of tibia	15.05	50.17	1.73	5.77	0.30
Length of keel	2.93	17.24	0.88	5.18	0.17
Height of keel	6.71	41.94	1.73	10.81	0.16
Length of tibia	4.12	11.44	2.74	7.61	0.36
Length of femur	16.25	52.42	1.05	3.39	0.31

* Necessary F at 5% = 3.11; at 1% = 4.88.

TABLE 4.—ANALYSIS OF VARIANCE OF BODY MEASUREMENTS AT 24 WEEKS OF AGE

	Between locations Mean Square (D/F = 2)	F*	Between origins Mean Square (D/F = 2)	F*	Error Mean Square (D/F = 85)
Growth	0.13	–	0.97	6.93	0.14
Breast angle	102.17	5.51	227.22	12.26	18.54
Circumference of tibia	0.38	1.58	0.29	1.21	0.24
Length of keel	3.20	17.78	3.92	21.78	0.18
Height of keel	1.65	9.71	3.36	19.76	0.17
Length of tibia	6.75	12.98	3.24	6.23	0.52
Length of femur	2.55	12.14	2.03	9.67	0.21

* Necessary F at 5% = 3.11; at 1% = 4.88.

In endeavouring to appraise the comparative effect of environment and heredity it becomes necessary to determine whether the differences between origins are significantly greater than those between locations, or vice versa. An analysis of the differences in growth (Tables 1 and 2) in detail and in the aggregate at 16 and 24 weeks of age indicate that at 16 weeks the differences due to environment were significantly greater than those due to heredity. At 24 weeks the differences due to hereditary factors were not significantly greater than those due to environment. Since, as shown by the variance tables a significant effect of both environment and heredity at 16 weeks has become a significant effect of heredity only at 24 weeks, it would seem that as maturity approaches the effect of environment becomes less apparent and the true hereditary body size more evident.

Body Measurements

The mean values for all body measurements are shown in Tables 5 and 6 for 16 and 24 weeks of age respectively. The analyses of variance for these same characters appear in Tables 3 and 4 for the same ages.

Breast Angle

The most important of the individual body measurements is breast angle since a full, rounded, as opposed to a sharp breast is essential for the higher market grades. The calculated breast angle used herein comes from the actual fitted angle of the breast and may be considered to represent an estimate of the angle formed by the two sides of the breast with the keel bone, which angle largely is determined by the skeletal breadth and depth of the breast segment of the bird plus the amount of fleshing on the breast. It has been found that the calculated figures for the breast angles of different birds very closely approximate the comparative visual or grading rating for conformation of breast. Perhaps the outstanding feature of the data on breast angle is the fact that at location B the cockerels of all strains had mature breast conformation at 16 weeks of age whereas at locations A and C there was a large and significant improvement in conformation between 16 and 24 weeks. This fact is further evidenced by the significant and consistent differences for all strains at B location over those at location A. At 24 weeks of age location C showed a tendency towards the production of greater breast angles although this superiority did not apply for the stock of strain A. It would seem therefore that some factor at the B environment tended to produce excellent breast conformation at an early age.

From Table 5 the average difference due to environment is significantly greater than that due to heredity thus indicating environment to be the most important factor. However, at 24 weeks of age, the effect of environment is no longer evident.

Circumference of Tibia

At 16 weeks of age *circumference of tibia* is significantly greater for all strains at location B. This may be considered to be largely a measure of degree of fleshing. It is gratifying to note that both measurements of conformation and fleshing viz. circumference of tibia and breast angle, are consistent in indicating environment B to have a very specific effect in bringing about an increased degree of fleshing and breast conformation during the period of rapid growth or at 16 weeks of age. At 24 weeks of age all such differences have disappeared for this measurement.

In this instance also, differences due to environment were significantly greater than those for origin at 16 weeks but not at 24 weeks.

Measurement of Keel and Long Bones

The mean values of Tables 5 and 6 show clearly that, while not consistent in every instance, significant differences occurred between strains and locations at 16 weeks of age in length of keel, height of keel, length of tibia or length of femur. On the average however, length of keel and length of femur are the only measurements in which differences due to environment significantly exceed those due to heredity and then only at 16 weeks of age.

TABLE 5.—MEANS OF BODY MEASUREMENTS AT 16 WEEKS OF AGE

Location		Breast angle			Circumference of tibia			Length of keel			Height of keel			Length of tibia			Length of femur		
		A	B	C	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C
Origin	A	34.4	41.9	38.3	11.5	12.9	12.0	10.9	11.2	11.6	10.6	11.4	11.6	16.6	16.1	16.9	10.7	11.8	12.1
	B	35.6	42.8	37.2	11.1	12.4	11.6	10.7	11.2	11.1	10.3	11.1	10.9	16.1	15.6	16.1	10.3	11.7	11.7
	C	33.5	44.7	40.9	11.2	12.7	11.9	11.1	11.4	11.6	10.5	11.2	11.4	16.1	15.8	16.6	10.7	11.8	12.2

TABLE 6.—MEANS OF BODY MEASUREMENTS AT 24 WEEKS OF AGE

Location		Breast angle			Circumference of tibia			Length of keel			Height of keel			Length of tibia			Length of femur		
		A	B	C	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C
Origin	A	41.5	42.4	42.5	15.0	15.0	14.7	13.4	13.0	13.8	13.0	13.3	13.7	18.5	17.5	18.2	12.9	12.8	12.6
	B	46.3	43.7	50.0	14.9	14.8	14.7	12.7	12.7	13.1	12.7	12.8	12.7	17.8	17.1	17.6	12.7	12.4	12.2
	C	45.0	44.4	50.2	14.9	15.0	15.0	13.6	13.3	13.9	13.0	13.1	13.4	18.4	17.5	18.2	13.5	12.7	12.6

DISCUSSION

Referring back to the introduction of this experiment it should be reiterated that the planning of the whole project was such as to make the issue very clearly one between the relative effect of heredity and environment upon the various characters such as growth and body measurements. By suitable statistical technique it was possible to divide the total effect into the portions attributable to inheritable factors, environmental factors, the interaction between these two factors, and to the residual effects which can neither be attributed to heredity nor environment but which actually are largely due to variability from bird to bird within sire groups under the same environment. A comparison of the residual effect with the hereditary and environmental effects permits the determination of which are significant or real effects and which are of chance occurrence. Also upon the basis of the magnitude of the differences due to environment and heredity a direct comparison of hereditary and environmental effects is possible from the data available. Since no untoward incident occurred to interfere with the carrying out of the project as originally planned the relative effect of heredity and environment were directly read from the data as analysed.

In the discussion which follows it should be borne in mind that the origins and environments upon which these findings are based are considered to be typical of well-fed, carefully managed, and well-bred poultry flocks under similar climatic conditions. The deductions made therefore are applicable to flocks where such conditions exist, which would include the majority of commercial enterprises but not farm flocks. It is safe to say that general farm flocks and marginal enterprises would be expected to show even more extreme effects of environment at least, and of breeding also to a lesser extent. A much greater effect of environment on the average over the whole poultry industry than has been experienced in this project might therefore be anticipated.

Growth

It is quite evident from the data presented that environment (Figure 3) had a much more marked effect upon growth than did heredity (Figure 2) during the period of rapid development from 4 to 20 weeks of age. A very interesting feature of the data is the fact that this position would appear to be reversed after 20 weeks of age as instanced by a greater and significant effect of heredity at 24 weeks of age. It may be presumed therefore that the course of the growth curve is largely dictated, during the early development of the bird, by environmental factors such as climate, housing, feeding and general management. As maturity approaches, however, either the environmental effects lessen or the genes governing size of the individual or strain exert an increasingly greater effect and may even govern the ultimate size of the individual. These conclusions are in keeping with the work of other investigators. Kempster (2) for example, instanced the effect of an environmental factor, temperature, in the retarding of growth and found that regardless of this retarding environmental effect during the growth period the body weight characteristic of the bird or strain was eventually reached.

Body Measurements

In most respects the data for body measurements follow closely those for growth. Again the effect of environment is marked and particularly so for breast angle. The outstanding example of this effect occurred at location B under which environmental conditions conformation of breast was superior for all strains at 16 weeks to that at the other locations and to such a degree that almost mature breast conformation was present under this environment at this age.

That this condition is largely one of fleshing is evident, and particularly is this so since skeletal structure as indicated by length measurements of keel and long bones did not differ significantly at this location from that at the others indicating the same skeletal size but greater weight and breast angle. Circumference of tibia, which is largely a measure of plumpness, confirms the evidence with regard to fleshing as instanced by larger breast angle, at location B.

Data which will be reported in a later communication indicate that on the average the pullets at location B regardless of strain came into egg production 22 days earlier on the average than those at locations A and C. Also, since the cockerels were on the average 9% heavier at 16 weeks of age at B location, it may be presumed that the greater breast angle was a direct reflection of rapid somatic maturity brought about by some one factor or some combination of the factors which form part of "environment" as here defined.

SUMMARY

An experiment planned to measure the comparative effect of heredity and environment upon growth and conformation in Barred Plymouth Rocks indicated:

1. Environment had a much greater effect than heredity upon the course of growth during the period of rapid development.

2. The relative effect of environment upon fleshing characteristics as indicated by breast angle (fullness of breast) and circumference of tibia was even more marked than upon growth.

3. Skeletal growth, as indicated by length of keel, height of keel, length of tibia and length of femur, differed significantly between different environments and different strains at 16 weeks of age indicating both an environmental and hereditary influence, the former having a greater effect on the average.

4. At 24 weeks of age no significant effect of environment upon body weight was apparent. The effect of heredity on the other hand appears to have become relatively more marked causing significant differences between strains for both body weight and breast angle. Apparently the environmental influence decreased somewhat whereas the influence of heredity became more marked at the approach of maturity.

5. Significant effects of both environment and heredity on skeletal size were apparent at 24 weeks of age. The effect of both factors was of approximately equal weight.

6. It would appear that in commercial strains of Barred Plymouth Rocks under good conditions of management control of growth rate and fleshing during the period of rapid development is largely dependent upon environmental factors such as feeding, housing and prevalence of disease. As maturity approaches, inheritable factors become more evident and environmental effects less apparent.

7. The strains and environments upon which these findings are based are typical of those prevailing on carefully managed poultry plants. Since environmental conditions on general farms and marginal enterprises would almost invariably be much less favourable than those of the poultry plants used herein, the greater effect of environment found in these data may be considered to be close to a minimum expression of that effect.

ACKNOWLEDGMENT

It is a pleasure to acknowledge the co-operation of the Experimental Stations at Charlottetown, P.E.I., and Harrow, Ontario. In particular the authors are indebted to Mr. B. F. Tinney of the Charlottetown Station and Mr. W. T. Scott of the Harrow Station, for the rearing of stock and the collecting of data throughout the course of the project.

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THE FEED REQUIREMENTS OF MARKET HOGS

A TENTATIVE FEEDING STANDARD[1]

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The problem of describing the total energy-yielding food required by an animal has been met largely by the preparation of feeding standards, of which there are several of practical usefulness. Feeding standards have been most used, however, for dairy cattle feeding. Hog feeding standards have never been greatly depended on by either the feeder or the professional animal husbandman. There are doubtless several reasons for this, but it is only necessary to compare the dairy and hog standards to fine one important difference affecting their relative usefulness.

All successful dairy standards recognize the fact that the total feed requirement is made up of two parts—the one depending on the size of the animal and the other on how much production is involved. Earlier standards which failed to take this dual nature of energy requirement into account have been largely discarded.

Hog standards on the other hand still suffer from this defect. The requirements are given according to size of pig with no reference to the rate of gain (i.e. production) involved. Such a standard is comparable to a dairy standard giving feed requirements for cows of different sizes but with an average level of production. This characteristic in itself makes such a standard practically useless as a guide to the feeding of market pigs where rates of live weight increase may range from little more than zero to two or more pounds per day.

It may be argued by some that, since market pigs may be full fed (and perhaps should be for optimum results), no feeding standard is needed. This argument implies that the only use of a feeding standard is to indicate how much feed should be provided for a given animal. A feeding standard has a broader usefulness than that, however. An especially important function which it should fulfil is that of a standard against which the efficiency of a given ration may be checked. To serve this purpose the standard must enable the feeder to calculate the feed requirement for the particular pigs in question—pigs that are not only of some particular size but pigs that are gaining at some particular rate.

To prepare a standard for the total daily feed requirement of pigs which will recognize both the "maintenance" and "production" requirement is theoretically quite feasible. If for the moment it can be assumed that feed (energy) requirements are proportional to some power of body weight, then the following equation should express the relationships involved between feed requirement, size of pig, and rate of gain:

$$Y = k + b_1(W)^n + b_2(G)$$

[1] Contribution from the Faculty of Agriculture, McGill University, Macdonald College, Que., Canada. Journal Series No. 163.

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[3] Assistant in Animal Experimentation.

where Y is feed in pounds, and b_1 and b_2 are partial regression coefficients of feed (Y) on weight $(W)^n$ and gain (G) respectively. There is evidence (Brody (1)) that the value of n is close to 0.73 for all mammals. Accordingly this figure was used in the preliminary phases of this study.

Such a standard will not indicate desirable protein levels. In the case of market pigs this may be of less consequence than at first thought. The chief factor necessitating a consideration of the protein level of the dairy meal mixture is the protein intake of the cow through feeds other than meal, principally the roughage. When the kinds and amounts of roughage are the same, the percentage of protein in the meal mixture for mature dairy cattle feeding need not be altered because of size of cow or varying production. The roughage complication does not enter into market hog feeding. Desirable adjustments of protein level of the hog diet are related to size (or probably more correctly the maturity) of pig.

Practical expression of this requirement is found in the use between weaning and marketing of the pig of two and sometimes three meal mixtures, differing essentially in protein level. A pig "starter" is recommended by some for the pigs for the month immediately following weaning. It is usually of relatively high (20 to 24%) crude protein content. When weaning is not done until the pigs are 8 weeks of age, tests fail to indicate the necessity for a pig "starter". The "growing" ration differs by carrying only 15 to 18% protein and is fed to growing pigs (following the period of feeding pig starter if such is used) until they weigh 100 to 125 pounds. From this time on a finishing ration carrying 14 to 16% protein is satisfactory.

Experiments indicate that other than for protein level, these two (or three) types of market hog rations are quite flexible as to make up within the restriction that softening fats and excessive fibre be avoided.

Indeed satisfactory hog feeding necessitates but two meal mixtures which may be described as follows:

TABLE 1.—MEAL MIXTURE FORMULAE

Class of pig	Basal feeds	Protein supplement	Mineral supplement
	%	%	%
Pigs from 8 weeks (weaning) to a weight of 100 lbs.	85	12	3
Pigs from 100 lbs. to market weight (200 lbs.)	90	8	2

The basal feeds may consist of barley (preferably not less than 43 pounds per bushel) or any combination of two or more such feeds as barley, wheat, oats, recleaned screenings, or corn, in which neither oats nor corn constitutes over 25% of the mixture.

The protein supplement may consist of a mixture comparable to:

50% meat meal or feeding tankage
30% linseed oilmeal or soybean oilmeal
20% fishmeal (preferably not over 9% fat)

The minerals may be supplied by some such combination as:

50% feeding bone meal
23% ground limestone
25% fine salt (iodized if desired)
2% ferric oxide or ferrous sulphate[4]

The question of skim or buttermilk will doubtless arise in dairy districts. In a sense these dairy by-products affect the nature of the meal ration needed for pigs in a manner similar to "roughage" in the dairy ration. The adjustment is easily made to allow for the use of either of these products, for they are not low protein feeds, as are the roughages, but represent high quality mixed protein-mineral supplements. In general, it may be considered that 10 pounds of either skim or buttermilk will replace 1 pound of a prepared protein-mineral supplement. Thus in the above formulae, 150 pound of either of these dairy products would replace the 12 pounds of protein plus the 3 pounds of mineral supplements. This leads to the further simplification in practical feeding that when 2 pounds of skim milk can be mixed with 1 pound of basal feeds no other protein-mineral supplement is needed.

It appears therefore that in lieu of data relative to optimum daily protein intake the requirement in this respect might with equal usefulness be expressed in terms of the protein percentage of the ration.

This raises the question of the terms in which the standard shall be expressed. Since of the losses in the gross energy of foods those in digestion are the largest and most variable, Total Digestible Nutrients might seem at first thought to be the logical choice. There is at least one objection to this plan, namely that digestibility data determined with pigs are relatively few. The Total Digestible Nutrient figures with which the majority of those employing feeding standards are familiar are based on ruminant digestion trials, and for many feeds the discrepancies between the response of ruminants and hogs in this respect are marked. Nor are the differences consistent as to magnitude or direction, as is seen in examples in Table 2.

TABLE 2.—PERCENTAGE TOTAL DIGESTIBLE NUTRIENTS OF CERTAIN HOG FEEDS*

Feedstuff	Digestibility trials involving	
	Ruminants	Swine
Barley	77	74
Corn	76	80
Oats	76	74
Wheat	76	73
Standard middlings	67	59
Soybeans	90	98
Linseed oilmeal	76	72
Fish meal	63	64
Tankage	46	70

* Food and Life, U.S.D.A. 1939 Yearbook.

[4] The iron probably need not be included for market pigs, but is included here because in practical feeding, the mixture to be fed to the young market pigs is frequently fed the nursing sow after the young pigs begin to feed with her before weaning. It has been found that supplementary dietary iron feeding is frequently advisable at this time.

Examination of the available digestibility data casts doubt as to whether various combinations of most cereal grains which are likely to form the basis of most market hog rations will alter the average digestible nutrients of the final ration over any greater range than is to be expected from different samples of the same feeds. Thus the net effect of using Total Digestible Nutrients would be a standard giving figures equal to a fixed fraction (approximately 73%) of the quantity of air dry feed required by the pig. The logical decision, therefore, was to express the feed requirements in terms of air dry feed.

The usefulness of the regression equation, $Y = k + b_1(W)^n + b_2(G)$, will obviously depend on how perfectly the feed consumption is determined by size of pig and his rate of gain in weight, and on how closely this equation can be made to fit data which may not be linear. This could be determined only by experiment.

The complete feed and live weight records for some 480 hogs were available from which to study this question. These pigs were all farrowed in the swine herd at Macdonald College and were of similar breeding. Their dams were related to each other as half sisters or as mother and daughter, and in any one season all pigs were by one of two sires. From weaning (8 weeks of age) to marketing (200 pounds live weight) the pigs were penned and fed individually. They were weighed and their feed consumption checked for the most part every 14 days.

At the outset it seemed clear that the only possible way of using the equation would be to break the feeding period up into sub-periods within which the curves of feed intake deviated only slightly from linearity. Since the data were available in 14-day periods beginning at an age of about 60 days, a preliminary grouping was based on these periods. Only one lot of 96 hogs was involved in this first work which was done principally to find out into what sections the feeding period would need to be separated. Thus, in the above equation W was the mean weight of the pig during the 1st, 2nd, 3rd, etc., 14-day periods, G was the daily gain and Y the daily feed during the same periods. The data for the first three 14-day periods were used, together with that of three other 14-day periods arbitrarily chosen to cover the balance of the feeding period to market weight. This grouping gave values of W, G, and Y as shown in Table 3.

TABLE 3.—MEANS OF WEIGHT, FEED AND GAINS BY GROUPS

Group	Mid weight		Daily gain	Daily feed
	W	$W^{.73}$	G	Y
	lbs.		lbs.	lbs.
1	37	14.08	0.68	1.99
2	49	17.16	1.03	3.04
3	60	20.40	1.23	3.72
4	90	26.85	1.56	5.11
5	115	32.05	1.79	6.26
6	155	40.04	1.71	7.10

For the first computation of the regression equations the weights of the pigs were all reduced to 0.73 power. (Subsequently the 1st power was used as will be later mentioned.) The regressions obtained in the preliminary study are given in Table 4.

TABLE 4.—REGRESSION EQUATIONS (PRELIMINARY TEST)

Group (Equation No.)	Equations $Y = k + b_1(W)^{.73} + b_2(G)$
1	$Y = 0.62 + 0.05(W)^{.73} + 0.96(G)$
2	$Y = -1.67 + 0.23(W)^{.73} + 0.71(G)$
3	$Y = -0.06 + 0.13(W)^{.73} + 0.87(G)$
4	$Y = -1.56 + 0.22(W)^{.73} + 0.56(G)$
5	$Y = 0.94 + 0.13(W)^{.73} + 0.69(G)$
6	$Y = 3.74 + 0.04(W)^{.73} + 0.96(G)$

Graphs of "observed" feed intake and observed daily gains were constructed at 10-pound weight increments for the daily gains and daily feed consumptions of the 96 hogs from which the regression equations were calculated. The curves were smoothed by fitting 4th degree polynomials to the original data. By substituting in the appropriate equation, a range of values for weight $W^{.73}$ and the corresponding rates of gain G as read from the polynomials of gain, the estimated feed requirement was obtained by solving for Y.

These calculated feed requirements are presented in Table 5 and are shown graphically in Figure 1.

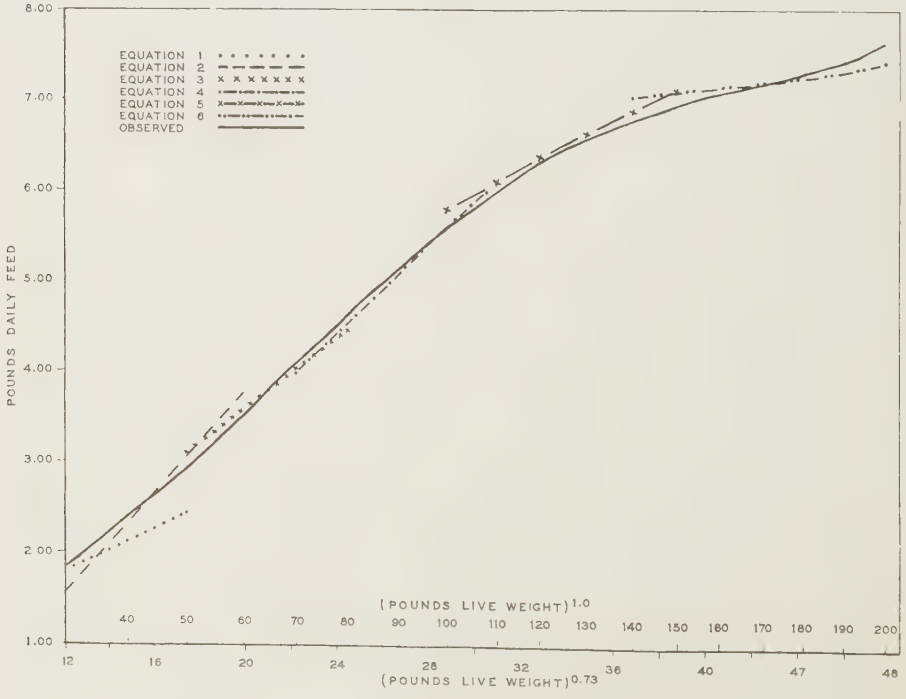

FIGURE 1. Calculated values for Y (see Table 5).

TABLE 5.—VALUES OF Y (FEED REQUIRED) ESTIMATED BY APPROPRIATE REGRESSION EQUATIONS FOR VARIOUS LIVE WEIGHT (W AND CORRESPONDING OBSERVED RATES OF GAIN G. (ALL FIGURES ARE POUNDS)

Live weights		Daily gain	Value of Y (feed required) (For equations used see Table 4)						Observed daily feed
W	$W^{.73}$	G	No. 1	No. 2	No. 3	No. 4	No. 5	No. 6	
30	11.98	0.59	1.8	1.5					1.8
40	14.78	0.78	2.1	2.3					2.4
50	17.39	0.97	2.4	3.0	3.1				2.9
60	19.87	1.15		3.7	3.6				3.5
70	22.23	1.32			4.0	4.0			4.1
80	24.51	1.46			4.5	4.5			4.6
90	26.71	1.58				5.1			5.1
100	28.84	1.67				5.6	5.8		5.6
110	30.91	1.74				6.1	6.1		6.0
120	32.95	1.78					6.4		6.3
130	34.92	1.79					6.6		6.6
140	36.87	1.78					6.9	7.0	6.8
150	38.78	1.76					7.1	7.1	6.9
160	40.64	1.73						7.1	7.1
170	42.48	1.70						7.2	7.2
180	44.30	1.67						7.2	7.3
190	46.08	1.67						7.3	7.4
200	47.83	1.70						7.4	7.6

The results of this preliminary study led to the tentative conclusion that the general scheme (at least for pigs over 75 pounds in weight) of estimating feed requirements from size of pig and rate of gain was feasible. However it was evident that the estimations did not fit the observed feed consumption satisfactorily for the newly weaned pigs.

The explanation for this discrepancy was believed to lie in the difference in the classification of data used in preparing the "observed" feed and gain figures as compared to that involved in the regression equations for the first three periods. The gains and feed intake shown as "observed" values are those of pigs at specific weights, while those on which the correlations and regressions were calculated are based on an age classification (i.e., as first 14 days from weaning). Thus while the average weight of pigs during the first 14-day period was 37 pounds and the mean daily gain 0.676 pounds, it did not follow that the mean gain of all 37-pound pigs was 0.676 pounds. This situation did not exist for the last three periods since the 14-day figures taken were determined by the arbitrarily set weight means of 90, 115, and 155 pounds.

In the preliminary study the correlations and regressions were calculated from the residual variances of the data from a single feeding trial so designed that effects of sex, season, and ration could be removed from the total variability. This seemed desirable where so few numbers were involved and with significant effects of grouping within the test. For equations applicable for a general feeding standard it was believed that "raw" gains and feed consumptions should be used and, of course, include a large enough number of pigs to provide a representative sample.

In view of the results of the preliminary study it was decided next to calculate regression equations of gains and live weight on feed consumptions for 14-day periods for weight groups from 45 to 75 pounds, 75 to 105 pounds, 105 to 135 pounds, and 140 to 170 pounds. For this purpose comparable data from 218 pigs were available. As in the preliminary study live weights were raised to the 0.73 power in accordance with the general finding that maintenance energy requirements are more closely related to this power of body weight than to its first power. These equations appear in Table. 6.

TABLE 6—REGRESSION EQUATIONS FOR WEIGHT GROUPS INDICATED

Group	Equation $Y = k + b_1(W)^{.73} + b_2(G)$
50 lbs.	$Y = -0.71 + 0.11(W)^{.73} + 1.73(G)$
60 lbs.	$Y = -1.28 + 0.20(W)^{.73} + 0.82(G)$
90 lbs.	$Y = -1.61 + 0.19(W)^{.73} + 1.02(G)$
115 lbs.	$Y = +0.56 + 0.13(W)^{.73} + 0.81(G)$
155 lbs.	$Y = +0.80 + 0.12(W)^{.73} + 0.77(G)$

For the "observed" values of feed intake and daily gain against which to test these regressions, data for 480 hogs were used, 4th degree polynomials being fitted to the raw data to smooth the curves. Feed requirements were calculated (using the appropriate regression equations) from the "observed" rates of gain at 10 pound increments of body weight. (See Table 7.)

TABLE 7—VALUES OF Y (FEED REQUIRED) ESTIMATED BY EQUATIONS OF TABLE 6

Live weight		Daily gain	Values of Y (feed required) (For equation see Table 6)					Observed daily feed
W	$W^{.73}$	G	50-lb. Group	60-lb. Group	90-lb. Group	115-lb. Group	155-lb. Group	
30	11.98	0.52	1.5	1.5	1.2			1.8
40	14.78	0.72	2.2	2.2	2.0			2.3
50	17.39	0.90	2.8	2.9	2.7			2.9
60	19.87	1.08	3.4	3.5	3.3			3.4
70	22.23	1.23	3.9	4.1	3.9			4.0
80	24.51	1.37		4.6	4.5			4.5
90	26.71	1.48		5.2	5.0	5.3		4.9
100	28.84	1.56			5.5	5.6	5.5	5.3
110	30.91	1.62			6.0	5.9	5.8	5.7
120	32.95	1.66			6.4	6.2	6.1	6.1
130	34.92	1.67				6.5	6.4	6.4
140	36.87	1.67				6.8	6.6	6.6
150	38.78	1.67				7.0	6.8	6.9
160	40.64	1.66				7.3	7.1	7.1
170	42.48	1.65				7.5	7.3	7.3
180	44.30	1.66					7.5	7.4
190	46.08	1.70					7.8	7.6
200	47.83	1.78					8.0	7.7

When the feed estimated by these regressions was compared to the observed values it appeared probable that an improvement in fit could be obtained at the lighter weights by using figures based on a 50-pound instead of the 60-pound mean weight of pig. It was also evident that the 115-pound group could be dispensed with. (See Tables 6 and 7.)

The feed estimates using the 50-pound mean weight were a slight improvement over the 60-pound grouping as seen in Table 7, and it seemed that by dividing the feeding period into three sub-groups the whole feeding period could be satisfactorily covered, using the regression equation based on 50-pound pigs for estimating feed requirements of pigs from weaning to 70 pounds; the 90-pound equation for pigs from 70 to 110 pounds; and the 155-pound equation for hogs from 110 pounds to market weight of 200 pounds.

There remained a possible simplification—namely, the use of live weight to the 1st instead of to the 0.73 power. The correlations and regressions were accordingly recalculated on this basis and yielded the equations given in Table 8.

TABLE 8.—REGRESSION EQUATIONS USING 1ST POWER OF WEIGHT

Group	Regression equations $Y = k + b_1(W) + b_2(G)$
50 lbs.	$Y = -0.19 + 0.04(W) + 1.09(G)$
90 lbs.	$Y = -0.10 + 0.04(W) + 1.03(G)$
155 lbs.	$Y = +2.09 + 0.02(W) + 0.77(G)$

The comparison between the use of W and $W^{.73}$ is shown in Table 9.

TABLE 9.—COMPARISON OF VALUES OF Y (FEED REQUIRED) ESTIMATED BY EQUATIONS OF TABLES 6 AND 8

$(\text{Weight})^{1.0}$	Observed daily gain	Observed daily feed	Values of Y from Equations of Tables 6 + 8		$(\text{Weight})^{.73}$
			$(\text{Weight})^{1.0}$	$(\text{Weight})^{.73}$	
30	0.52	1.8	1.6	1.5	11.98
40	0.72	2.3	2.3	2.2	14.78
50	0.90	2.9	2.9	2.8	17.39
60	1.08	3.4	3.5	3.4	19.87
70	1.23	4.0	4.0	3.9	22.23
80	1.37	4.5	4.5	4.5	24.51
90	1.48	4.9	5.0	5.0	26.71
100	1.56	5.3	5.5	5.5	28.84
110	1.62	5.7	5.9	5.8	30.91
120	1.66	6.1	6.1	6.1	32.95
130	1.67	6.4	6.4	6.4	34.92
140	1.67	6.6	6.6	6.6	36.87
150	1.67	6.9	6.8	6.8	38.78
160	1.66	7.1	7.1	7.1	40.64
170	1.65	7.3	7.3	7.3	42.48
180	1.66	7.4	7.5	7.5	44.30
190	1.70	7.6	7.8	7.8	46.08
200	1.78	7.7	8.1	8.0	47.83

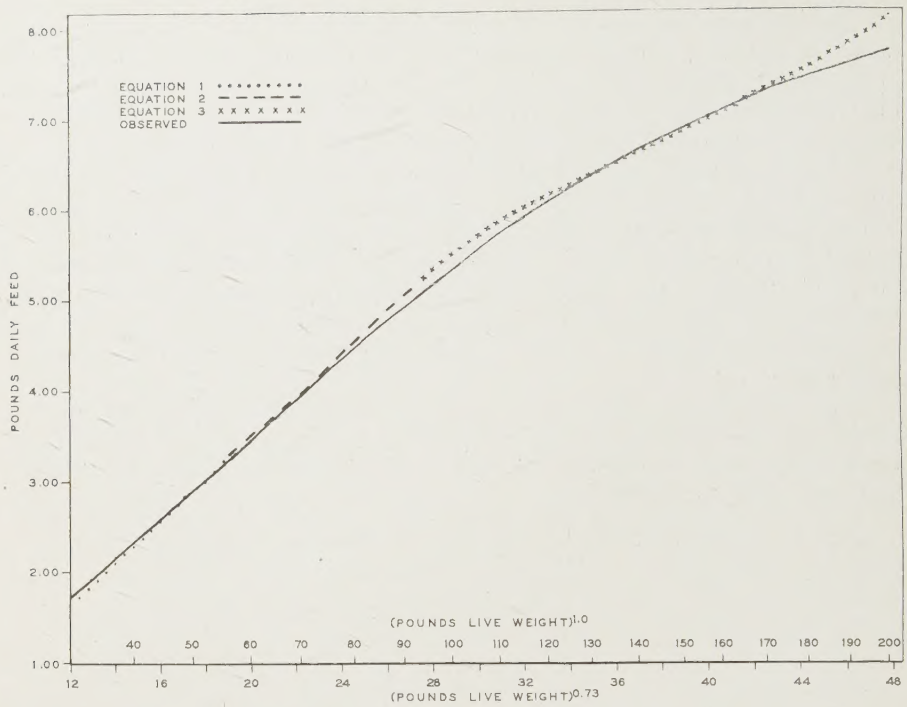

FIGURE 2. Calculated values for Y (see Table 9).

It is evident that if anything the choice in fit lies with the 1st power of weight. Since this is also considerably simpler for practical use it was the obvious choice. The goodness of fit of the "observed" and "predicted values" is shown in Figure 2.

PROPOSED HOG FEEDING STANDARD

On inspection of the regression equations (Table 8) the similarity of the b values in the 50-pound and 90-pound groups is seen. While the regression coefficients are slightly larger for the 50-pound group, the k value is also greater. Hence values of Y for either the 50-pound or the 90-pound group calculated by either of these formulae with the same values of W and G give almost identical figures. Furthermore it was found that ignoring the small negative k values and using $b_1 = 0.04$ and $b_2 = 1.0$ altered the calculated values of Y but slightly and gave practically as good a fit to "observed" feed as the original formulae. Evidently the feed requirement for pigs from weaning to 110 pounds could be predicted from this simplified equation.

In the case of the 155-pound group, it was found that for practical purposes, satisfactory values for Y could be obtained by simplifying the equation so that,—

$$k = 2.0 \text{ lbs.}$$
$$b_1 = 0.02 \text{ lbs.}$$
$$b_2 = 1.0 \text{ lbs.}$$

Comparison of the observed feed and that calculated by the regression equations simplified as above indicated is shown in Table 10 and Figure 3.

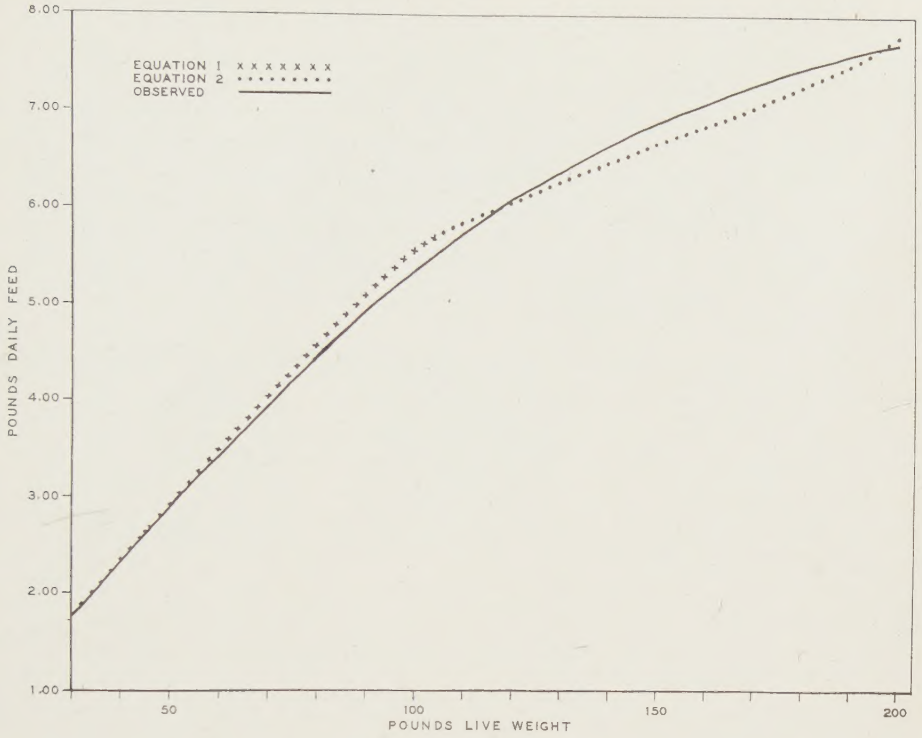

FIGURE 3. Calculated values for Y (see Table 10).

TABLE 10.—OBSERVED AND CALCULATED FEED CONSUMPTION (POUNDS) BY MARKET PIGS

Size of pig	Observed daily gain	Observed daily feed	Values of Y (feed required)	
			$Y = 0.04(W) + 1.0(G)$	$Y = 2+0.02(W)+1.0(G)$
30	0.52	1.8	1.8	
40	0.72	2.3	2.3	
50	0.90	2.9	2.9	
60	1.08	3.4	3.5	
70	1.23	4.0	4.0	
80	1.37	4.5	4.6	
90	1.48	4.9	5.1	
100	1.56	5.3	5.6	
110	1.62	5.7		5.8
120	1.66	6.1		6.1
130	1.67	6.4		6.3
140	1.67	6.6		6.5
150	1.67	6.9		6.7
160	1.66	7.1		6.9
170	1.65	7.3		7.1
180	1.66	7.4		7.3
190	1.70	7.6		7.5
200	1.78	7.7		7.8

It should be pointed out that the calculated feed requirement applies only to pigs of the weight indicated ± 5 pounds. Thus the calculated

feed for an 80-pound pig would apply while the pig ranged from 75 to 85 pounds. Because of the large standard deviation of weights of pigs at given ages, it is not feasible to attempt to establish age classes corresponding to weight groups, and thus to apply this "standard" according to age of pig. It may also be noted that the portion of feed calculated as $- b_1(W) -$ is not a maintenance requirement in the technical sense of the word and there is no evidence from these data that this value approaches such a requirement. It is merely the "partial relation" shown by changes in size of pig to the total day's feed. It is probably coincidental that the value of b_1 is 0.04 for pigs under 100 pounds and that the feed requirement for mature sows is 4% of their live weight.

The feeding standard which in the light of this study is proposed is shown in Table 11.

TABLE 11.—MARKET PIG FEEDING STANDARD

Weight of pig (lbs.)	Crude protein needed in feed, %	Pounds daily feed (air dry weight)
30 to 100	15 to 18	(0.04 × wt. of pig) + (lbs. gain per day)
100 to 200	14 to 16	(0.02 × wt. of pig) + (lbs. gain per day) + 2 lbs.

REFERENCE

1. BRODY, S. and U. S. ASHWORTH. Growth and development with special reference to domestic animals. XXXIV. Mo. Agr. Exp. Sta. Res. Bul. 220. 1934.